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Editorial

Traditionally all abstracts of contributions submitted to the 22nd General Assembly are included free of charge in the *Abstract Book* once they were accepted by the appropriate convener(s) and once they were received by February 1997, i.e., about two months *after* the deadline, and in the standard format and of sufficient quality for reproduction. Abstracts submitted for symposia sponsored by two Sections included in different parts of the *Abstract Book* are included (twice) in both parts, respectively.

Like in previous years, not all contributions included will actually be presented. Because of the lack of financial support, several young scientists as well as colleagues from the central and east-European countries will not be able to participate in the meeting, although the Society has continued its support schemes, such as the Young Scientists' Travel Award and the East European Support Award. In this way there are more abstracts included in the *Abstract Book* than contributions compiled in the *Programme Book*. Therefore, in order to simplify the ordering of abstracts within a symposium, we have adopted the alphabetical order with respect to the surname of the first author rather than the order of presentation.

With more than 4.300 contributions received, the *Abstract Book* has become an open forum for fast distribution of results of geophysical research on a pan-European, international level, helping, at the same time, to promote the contact between all geophysicists in Europe. Please, support the fostering of cooperation and contact your colleagues also if not personally present this time.

On behalf of the Society I am very pleased to welcome you to Vienna on the occasion of the 22nd General Assembly of the European Geophysical Society. May your participation in this meeting be successful and scientifically rewarding.

A.K. Richter
Executive Secretary

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SOCIETY SYMPOSIA (EGS)

EGS1 Joint inversion as a general problem in Earth sciences

Convener: Ballani, L.
Co-Conveners: Martinec, Z.; Strykowski, G.; Weidelt, P.

THE CONSEQUENSE AND CAUSE OF GEOLOGICHEN PROZESES OF THE NEW CONCEPT FOR OIL FORMATION

Valentina Berkovska (Ukrainian State Geological Prospecting Institute, Geophizical Department, Kyiv, Ukraine)

The process of geological and geophysical investigations is the simulation process on the basis of sciences interconnections.
The synthesis of the scientific knowledge and practical skills enables to construct the model of the natural object as one of the forms for the visual representations of the geological object.
Presenting the concept for oil formation in nature under the influence of the natural radioactivity it is for the 1-st time (1983) asserted by the author using the energetic approach that the gaseous HC are to be of primary origin and those of complex composition — of secondary (without the definite connection with organic or inorganic source of the gaseous HC formation).
Therefore, the problems of geotectonics, facies analysis, phase analysis of hydrocarbons, formation of natural hydrofracture of the bed, anomalous formational pressure and others are in particular must make up mind.

CLIMATE CHANGE INFERRED FROM BOREHOLE TEMPERATURES: HOW TO IMPROVE THE SOLUTION BY USING ADDITIONAL INFORMATION

L. Bodri (Geophys.Dept., Eötvös Univ., Budapest, Ludovika 2., Hungary 1083)
V. Čermák (Geophys.Inst., Czech Acad.Sci., Praha 4, 141-31 Czech Republic)

Past climate changes have caused certain perturbations in the subsurface temperature field. Their inversion yields the time variations of the ground surface temperature (GST), which however may be highly non-unique. To incorporate additional information on the behaviour of the unknown function may usually help a lot to treat the non-uniqueness. The traditionally used information imposing bounding and smoothing contraints on climatic history can be further significantly extended by including stochastic properties of climate. It was shown that climatic records reveal: (1) long-term persistence of climate, and (2) high intermittency of climate variations characterized by hyperbolic decrease of probability tails. We have quantified and incorporated such information into the inversion method in the form of the covariance matrix of the unknown parameters. Inversion of near 100 temperature-depth profiles from the Czech Republic provided more meaningful climatic histories in comparison with simple inversion and increased the time span that clould be resolved. The effectiveness of the method is illustrated on the borehole Holubov in Southern Bohemia. While the simple inversion permitted to resolve only 3 climatic events and recovered the GST history to about 1700 A.D., incorporation of the additional information increased the number of resolvable events to 7 and disclosed climatic history back to 1000 A.D.

INTEGRATED INVERSE MODELLING ON THE BASIS OF GRAVITY AND SEISMIC DATA

V. Glaznev (Geological Institute, Kola Science Centre RAS, Fersmana, 14, 184200 Apatity, Russia)
A. Buyanov (Mining Institute, KSC RAS, Fersmana, 24, 184200 Apatity, Russia)

A consistent integrated model of a medium is a model that conforms to all the observed geophysical fields and has definite relationships between the unknown medium properties. The simultaneous solution of the inverse problems for the seismic and gravity methods have been used as an iteration procedure. The results of the inversion in one geophysical method served as initial model for inversion task in another geophysical method and vice versa. As a result of one step of the integrated inversion the interrelated density and velocity models of the studied medium can be obtained. The solution precision is estimated from the discrepancy between the observed and calculated fields. If the precision of the solution does not satisfy to the *a priori* r.m.s. differences of the fields (travel time, gravity field), the interpretation may be repeated on the next step in order to ascertain the complex solution in velocity-density values. This process is, in general, convergent and allows us to obtain a satisfactorily precise solution of the integrated inverse problem, the number of iterations being low. This approaches based on interrelation between the physical properties of the medium. These interrelations should be determined *a priori* for the rock types that are found in the study region. In a general case, they have a probabilistic nature rather than functional one. The probabilistic characteristics of these interrelations are a basis for solving inverse problems with system of the weighting functions. The 2D and 3D results of the integrated modelling are shown.

DEPENDENCE OF ROCKS PROPERTIES AND DEFORMATION PROCESS ON STRUCTURAL INHOMOGENEITIES - THE RESULTS OF TECTONOPHYSICAL MODELING.

Talitskii V.G. and Galkin V.A. (119899, Geol.Dpt.Moscow State University, Vorobiovy Hills, Moscow, Russia)

Continuous homogeneous descriptions of geological medium are shifted, today by discrete models. In terms of discreteness the tectonosphere is the hierarchic system of structural elements of different scales. The stresses concentrates on previous structural inhomogeneities of different scales. Strain is localized in concentrators zones and changes the structure. Thus, the tectonic strain mechanisms should be considered to be the processes of dynamic reconstruction of previous hierarchic structure "trying" to dissipate tectonic energy. Tectonophysical modeling on rocks analogues may be used to study the impact of previous structures to deformation. We made sets of cuts (the boundaries of grain, layer and block elements) in homogeneous clay pastes layer according to the type of a previous structure, i.e. we created the structural inhomogeneities. Structural patterns we got depend on elements morphology, their dimensions and orientation to stress axes. The main mechanisms are pure shear of elements, bending and rotation, rapture and combination of these mechanisms. We perceived the formation of elements of newly appeared structural levels and their further participation in deformational process. Rocks analogues "rheology" (and thus, the rocks physical properties) depends on parameters of structural inhomogeneities.

INTERPRETATION OF NMR SURFACE DATA BY COUPLED MAXWELL AND BLOCH EQUATIONS

J. Gottlieb (Forschungszentrum Umwelt, Universität Karlsruhe, D-76128 Karlsruhe)
S.I. Kabanikhin and V.G. Romanov (Institute of Matematics, Russian Acad. of Science, Novosibirsk)

Surface NMR methods for water prospection are a quite new geophysical tool. It uses the property of hydrogen nuclei which produce a magnetic field when they are excited in their resonance frequency. This frequency is for the background Earth magnetic field of about 2.2 kHz. The measured response of the resonance excitation mainly depends on the distribution of the following parameters: electrical conductivity, initial magnetization (which is proportional to the water content) and the relaxation time T_2 that corresponds to the pore size. We formulate the inverse problem on the basis of coupled transient electromagnetic equations and Bloch's equations. We analyse the inverse problem for a layered medium and present first numerical results.

INVERSE PROBLEMS OF ELECTROMAGNETOELASTICITY

S.I. Kabanikhin (Institute of Mathematics of Siberian Branch of Russian Academy of Sciences, 630090 Novosibirsk, Russia)

During the last 25 years a lot of papers have been published describing the connection and conversion of seismic to electromagnetic energy and waves in geological environments and the detection of the electric or magnetic signals as a method of geophysical exploration. However the phenomena involved in the conversion of seismic energy and waves to electromagnetic energy and waves are not fully understood.
This problem needs both the experimental and theoretical investigations. For example, if an elastic electroconductive medium is imbedded in an electromagnetic field, then the elastic oscillations propagating through the medium will exite oscillations of the electromagnetic field and themselves will change under the influence of the latter. The waves arises as a result of such an interaction are usually referred to as magnetoelastic. We describe the theoretical analysis of the joint inversion of the coupled system of electrodynamics and elasticity, the structure of the Cauchy problem solution in the case of point sources. We also demonstrate the examples of numerical joint inversion for the system of electromagnetoelasticity with unknown source of elastic oscillations.

A STUDY OF GLOBAL SCALE INVERSE PROBLEMS BASED ON AN ATMOSPHERIC TRANSPORT MODEL AND ITS ADJOINT

T. Kaminski, M.Heimann and R.Giering (Max-Planck-Institut für Meteorologie, Bundesstr. 55, D-20146 Hamburg)

TM2 is a global three-dimensional model of the atmospheric transport, using prescribed soures and sinks to integrate the concentration of any passive tracer in time. The determination of the sources and sinks of e.g. CO_2 from observations of its atmospheric concentration constitutes an underdetermined inverse problem. In order to get unique solutions, additional independent information about the CO_2 fluxes from models of the terrestrial biosphere, the ocean and fossil fuel burning is included in the inversion procedure. By means of the Tangentlinear and Adjoint Model Compiler (TAMC) an adjoint model of TM2 and of the coupled model TM2-SDBM (Simple Diagnostic Biosphere Model) has been constructed automatically. Employing CO2 as an example of a chemically inert tracer we demonstrate the benefits of the adjoint approach in terms of computational cost for both linear and nonlinear problems. For linear problems, depending on the dimensions of the model matrix which relates sources to concentrations at the observation locations, computation in adjoint mode can be shown to be often much more efficient than forward modeling. In the nonlinear case efficient minimisation algorithms require derivative information which can be provided by the adjoint model.

SEISMIC VELOCITY-DENSITY RELATIONSHIP : A CRITICAL REVIEW

E.E. Klingelé (Institut für Geodäsie und Photogrammetrie, ETH Hönggerberg, CH 8093 Zürich, Switzerland)

For the past decades Earth modelling based on seismic velocities (Vp) and gravity anomalies has been an important topic in geophysical research. In many cases seismic and gravimetric models are not concurrent because of the scatter in the relationship used for transforming the seismic velocities into density.
Up to now, largely speculative explanations for these discrepancies have been proposed. A critical review of the principal velocity-density relationship is presented and another approach is proposed to explain the above findings, assuming that rheological effects have to be taken into account in the conventional velocity density relationship. The most important parameters affecting the seismic velocities are : porosity, fluid content, type of fluid filling the pore space, temperature and mechanical stress. A quantitative evaluation of their effects shows that in certain cases the seismic velocity can vary by up to 20 percent whereas the density varies no more than one percent. It is proposed to use the discrepancies between gravity and seismic models for evaluating the rheological parameters of the Earth's crust.

JOINT INVERSION USING SIMULATED ANNEALING IN 2-D: II. THE VLF MODE

P.Kaikkonen (Department of Geophysics, University of Oulu, Oulu, Finland)
S.P. Sharma (Department of Geophysics, University of Oulu, Oulu, Finland)

VLF-EM (Very Low Frequency) data have been widely used for reconnaissance studies of shallow conducting subsurface targets. So far, inversion of the VLF data has not been considered to obtain precise subsurface conductivities and geometries, inspite of the availability of forward solutions for multidimensional structures. Therefore, as a continuation of our previous study concerning joint inversion using simulated annealing in 2-D for the VLF-R mode, global optimization of the VLF data (real and imaginary anomalies) alone and jointly with VLF-R data was considered in this paper.

This study reveals that individual inversion of either real or imaginary anomalies does not yield a model which would fit the both observations. However, the joint inversion of the both data sets yields the model which fits the both observations. Comparing VLF inversions to VLF-R data shows that both the individual and joint VLF inversions have a better agreement with the apparent resistivity data than with the phase data. Conversely the joint inversion of the apparent resistivity and phase data yields the models which also have a good agreement with the real and imaginary anomalies. The joint inversion of all the VLF and VLF-R data was also performed. The results obtained after such an inversion show a good agreement with all the data sets. However, the combining of all four data sets is rather crucial because it requires all the individual objective functions to be made to the same level.

THE INVERSE PROBLEM FOR MANTLE CONVECTION SYSTEM EQUATIONS

Yu.V.Khachay,O.A.Hachay (Institute of Geophysics,RAS,Amundsen Str.,100,620016,Ekaterinburg,Russia)

The question of physical mechanisms,which create a slow matter flow and convective structures formation is a central problem of Earth's mantle convection research.For selection of the most probable convection mechanisms mathematical simulation is usually used. It had been derived numerical solutions of theoretical examples for a direct problem of the convection equations system.It had been showed that the use of magnetotelluric sounding profile data interpreta tion results and calibration relations of mantle's matter conductivity from temperature had allowed to determine the structure created by thermal mechanism of convection and to fix the difference from other physical mechanisms.
It had been formulated an inverse problem of koefficient type for identification convection mechanisms in the Earth's Mantle. We had derived new equations of the inverse problem,for which we can use data of deep EMS. On numerical experiments we had researched the informativity and the degree of constructivity of that way. We had obtained a parameter - the local Reley number, by which we can identificate different convection mechanisms. Mathematically that approach can be used for solving inverse problems,linked with heat-mass transport in disperse filtration mediums.

MIPAS USED AS A NON-LTE SOUNDER FOR NO 5.3 um BAND

V.S.Kostsov and Yu.M.Timofeyev (Research Institute of Physics at St.Petersburg State University, Ulyanovskaya 1, St.Petersburg-Petrodvorets, 198904 Russia)
H.Fischer and G.Stiller (Institut fuer Meteorologie und Klimaforschung, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany)

The space-borne MIPAS experiment has been numerically simulated in the 5.3 um spectral domain, and the possible non-LTE emissions from NO have been investigated. The interfering non- LTE contributions from H2O, CO2, and O3 to atmospheric limb radiances have been estimated. The inverse problem has been formulated for the joint retrieval of the NO vertical profile and the vibrational temperatures of the NO lower vibrational states. The optimal estimation technique has been selected as a tool for the evaluation of the retrieval accuracy of NO number density and vibrational temperature vertical profiles. The error matrix calculations have shown that the retrieval accuracy for NO concentration is 30-40% in the altitude region 10-50 km, but can be improved by 10% if averaging of spectra is performed to achieve low noise. The retrieval accuracy for the vibrational temperatures of the X1/2-1 and X3/2-1 states was estimated to be better than 10 K in the stratosphere, but for the states X1/2-2 and X3/2-2 it appeared to be rather poor. The problem of NO vertical profile retrieval in the non-LTE atmosphere is discussed. It was shown that in order to obtain a reasonable accuracy of NO retrieval of 20% up to 50 km altitude it is necessary that the a priori uncertainty of the vibrational temperature of the state X1/2-1 should not be higher than 5 K.

3-D MAGNETIC DATA INVERSION "JOINT" ALGORITHM

P.S. Martyshko, K.V. Musygin (Institute of Geophysics, Ural Branch of Russian Academy of Science, 620016, Ekaterinburg, Amundsen str. 100, Russia)

The algorithm for solving of 3-D inverse problem of magnetic investigation with the account of demagnetization in linear statement was developed and realised (seeking the magnetization of the object when its form is given). The explicit operator equation for the nonlinear inverse problem was obtained (seeking the object form with the given constant magnetization). The algorithm of solving of this equation was realised. "Joint" algorithm of determining the object form and its variable magnetization on the base of these results was developed: 1) approximation of the observed data with the fields of singular sourses and construction of equivalent objects with constant magnetization; 2) variable magnetization of constructed equivalents determination. The algorithm was successfully tested on a number of model examples.

ON 3-D NONLINEAR ELECTROMAGNETIC INVERSE PROBLEM

P.S. Martyshko, A.L.Rublev (Institute of Geophysics, Ural Branch of Russian Academy of Science. 620016, Ekaterinburg, Amundsen str. 100, Russia)

We have obtained the new inverse problem equations of electromagnetic field. There are the first generation equations with explicit operators.The primary field sourse can be arbitrary type. Uniqueness of representation is shown. The method for solving of 3-D nonlinear electromagnetic inverse problem was diviced (in the cases potential and monochromatic fields). It's based on the algorithm for solving explicit equations of the 3-D inverse problem. We apply the Tikhonov regularization method to 3-D EMD inversion. As a result of interpretation we obtain the bodies stellate relative to some point with different values of conductivity which generated the same (electrical or magnetic) field. We have studied the possibilities for uniqueness solution seeking on the based joint interpretation of diffrent EMD. We have some examples with good results of interpretation.

Geodynamic models as the basis for joint interpretation of geological and geophysical data.

V. Mikhailov (United Institute of Physics of the Earth RAS, B. Gruzinsakya 10, Moscow 123810, Russia)

Our approach is based on construction of models of formation of tectonic structures. These models provide relationships between different data such as topography, thickness and physical properties (density, elastic modules, viscosity) of the layers, thickness, depth of deposition, and age of sediments, rate of subsidence or uplift, stresses, heat flow, gravity field etc. Using this models the joint interpretation of any geological and geophysical data reduces to determination of almost the same parameters of geodynamic model. Our numerical calculations have shown that the accuracy of determination of model's parameters is high and that the validity of interpretation depends mainly on the fit of the model to the real tectonic process. This approach was applied to the analysis of the data on platform sedimentary basins and passive margins. For example, for the Russian platform the model of viscous sedimentary layers deforming by rigid basement blocks has been employed. The relief of the uppermost sedimentary layer specified by seismic and borehole data and gravity anomalies were given. The basement topography and interfaces within sedimentary cover, average density and viscosity of sedimentary layers and density of basement rocks were determined. It has been demonstrated that the solution of this inverse problem is unique and stable.

AN INVERSE SOLUTION TO THE OLD PROBLEM OF MANTLE VISCOSITY

J. X. Mitrovica (Department of Physics, University of Toronto, Canada, M5S 1A7, 416-978-4946, jxm@physics.utoronto.ca)
A. M. Forte (Institute de Physique du Globe de Paris, Dept. de Sismologie, 4 Place Jussieu, Paris 6, 75252 France)

The radial viscosity profile of the Earth's mantle strongly influences the dynamics of flow in the planetary interior and the manifestation of that flow on surface geophysical observables (e.g., tectonic plate motions, dynamic topography). Not surprisingly, the inference of mantle viscosity is a classic problem in geophysics; unfortunately, the history of the subject is characterized by discord and controversy. Part of this dispute arises because inferences based on two distinct data sets, related to post-glacial adjustment and mantle convection, appear to be incompatible, with the latter suggesting a significantly higher viscosity increase with depth than the former. In this talk we present results of the first joint inversions for mantle viscosity of post-glacial rebound and mantle convection observables (see Forte and Mitrovica, Geophys. Res. Lett., 1996; Mitrovica and Forte, J. Geophys. Res., 1997). These inversions, based on a non-linear, iterative, Occam methodology (Constable et al., Geophys., 1987), indicate that both data sets can be reconciled by a single profile of mantle viscosity which is characterized by a significant (factor of about 30) increase with depth across this region. The joint inversions thus resolve an outstanding problem in mantle dynamics.

JOINT INVERSIONS FOR MANTLE VISCOSITY

W.R. Peltier (Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7)

The inverse problem for mantle viscosity is intrinsically one on which a wide range of distinct types of information may be brought to bear. Even restricting consideration to the glacial isostatic adjustment process, there exist the following unique data types: (1) distinct relaxation times corresponding to specific wavenumbers in a relaxation spectrum (e.g. the data inferred from the observed postglacial rebound of Fennoscandia by McConnell 1968), (2) distinct relaxation times deduced on the basis of ^{14}C dated relative sea level histories for specific longitude - latitude locations on the Earth's surface that were once ice covered, (3) data related to anomalies in Earth's current rotational state (the non-tidal acceleration of rotation and the "true-polar-wander" of the rotation axis with respect to a frame of reference fixed to the crust). For the first time a large sample of such data has been jointly inverted using the methods of Bayesian inference to determine a maximum likelihood model and to assess the extent to which individual features in the retrieved profile are resolved by the data (W.R. Peltier, Science, 273, 1359-1364, 1996). The mlm has been shown to possess significant capacity to correctly predict observations not employed to derive it. In particular the model appears to automatically satisfy observations related to the mantle convection process (non-hydrostatic geoid anomalies), especially when it is further refined by jointly inverting this additional data set. The fact that the model successfully reconciles both long timescale (convection) and short timescale (rebound) constraints has the profound implication that mantle rheology is not significantly transient and therefore that it is essentially Newtonian.

POTENTIAL FIELD DATA INVERSION FOR THREE-DIMENSIONAL OBJECTS OF ARBITRARY SHAPE

I.L.Prutkin (Institute of Geophysics, Amundsen St. 100, 620016 Ekaterinburg, Russia)

The preliminary condition for joint inversion is,from the author viewpoint, to solve every inverse problem in the best way, that is with taking into account the non-uniqueness of the solution and for 3D objects of arbitrary shape. Developed are theoretical foundations, numerical algorithms and computer programs to find a geometry of 3D restricted body, one or several 3D contact surfaces. It should be emphasized, that we managed to avoid any modelling: new integral equations of the first kind have been derived to find a function determining a geometry of the object sought. The method of local corrections has been suggested, which makes it possible to curtail the time required to solve an inverse problem approximately by an order of magnitude. Our technique has been successfully used in global, prospecting and mining geophysics. Joint inversion of gravity and magnetic data for core mantle boundary relief led us to some hypothesis on the core material flow. 3D relief of the upper boundary of pre-jurassic rocks was found using square gravity data mainly. Subsequent comparison of the relief obtained with the position of the boundary according to the seismic profile, unknown for the author beforehand, has revealed their quite satisfactory coincidence. New algorithm was derived to find 3D relief of conductivity contrast surface. It could be used together with our algorithm for gravity data inversion to recover lower boundary of sedimentary rocks.

A METHOD LITHOSPHERE DENSITY MODELING FROM GRAVITY, SEISMIC, GEOID, AND LOCAL ISOSTASY DATA

T.V. Romanyuk (IPE, B. Gruzinskaya 10, Moscow 123 810, Russia)

A method of lithosphere density modeling from the geoid, gravity, seismic, and local isostasy data is presented. The main idea of the method is to get a set of possible density models with the gravity and geoid data inversion (2-D or 3-D), using the following constrains: 1) adequation of the shape of the density boundaries to the seismic ones; 2) the limits on the determined densities, estimated from bore hole and seismic velocities data; 3) maintenance of isostatic equilibrium; 4) correlative relations between seismic velocities (Vp & Vs) and densitiy. A solution is reached by minimization of the summary functional:

$$F(\rho) = G + \alpha H + \beta P + \gamma W = \min, \quad \text{with condition} \quad \rho_1 < \rho < \rho_2,$$

ρ_1 and ρ_2 - upper and lower limits for the defined ρ densities of the model;
G and H - discrepancies between the calculated and observed gravity fields (G) and geoids (H);
P - standard deviation of pressure at the chosen (isostatic) level (or levels) for indicated parts of the model;
W - functional, describing the measure of deviation of velocity-density relations from linear (ρ=a Vp +bVs +c) ones in the marked parts of the model;
α,β,γ - weight coefficients (or stabilization parameters).
Comparison of the solutions, obtained at different weight coefficients, alows to find some stable macro-characteristics of the density distribution. The modifications of the method were applied to density modeling of the platform areas of Eurasia, Northwest Pacific subduction zone and Mid-Atlantic ridge.

IMPROVING THE QUALITY OF NONLINEAR GRAVITY INVERSION BY USING GEOMETRIC PRIOR INFORMATION

U.Schäfer (Institut für Angewandte Geodäsie, Außenstelle Potsdam, Michendorfer Chaussee 23, D-14473 Potsdam, Germany)

By employing exclusively gravimetric data it is impossible to overcome the fundamental problem of non-uniqueness and instability of inverse gravity solutions. In order to reduce the practical ambiguity one is therefore obliged to use as much additional prior information as possible. On the other hand the solution (or even the formulation) of a classical extreme value problem with a large number of different parameter constraints is often hard to deal with.
By using so-called assembling source classes in the frame of a gravity inversion approach it is comparatively simple to consider in a flexible way various pieces of prior information with respect to source distribution, in particular geometrical prior information (e.g. compactness, degree of connectedness, does a certain area/cell belong to a source body or not, etc.) The geometric prior information is ciphered by a specific property code attributed to the elementary cells. Here the space wherein the solution has to be sought is formed by a set of elementary cells. This approach was proved by using synthetic field data with a certain noise level and different kind of geometrical prior information. We use geometric criteria to estimate the deviation between an obtained solution and the "real" source distribution. Applying these criteria it can be shown, that the quality of the nonlinear inverse solution will be the better and the method will work the faster the more pieces of geometric prior information will be added.

JOINT INVERSION USING SIMULATED ANNEALING IN 2-D: I. THE VLF-R MODE

S.P. Sharma[1] (Department of Geophysics, University of Oulu, Oulu, Finland)
[1] On leave from Rajasthan Groundwater Department, Udaipur, India
P.Kaikkonen (Department of Geophysics, University of Oulu, Oulu, Finland)

The data associated with 2-D Earth structures have been used to demonstrate the efficacy of the VFSA (very fast simulated annealing) with finite element modelling in the inversion process. The VLF-R (Very Low Frequency -Resistivity) data, i.e. the apparent resistivity (ρ_a) and phase (φ) data, have been inverted individually and jointly for a number of models to yield the physical and geometrical parameters of the targets. To represent measured data synthetic responses with different amount of random and normally distributed Gaussian noise have been inverted. VLF-R field data have also been inverted to demonstrate the efficacy of the approach in delineation of the parameters of 2-D structures.

Global inversion results reveal that neither the inversion of the ρ_a nor φ data alone yields the true parameters of the structures. However, the joint inversion of the ρ_a and φ data yields very good estimates of the model parameters. Various models achieved after multiple VFSA runs have been used to compute the mean model and the corresponding covariance and correlation matrices which have been used to estimate the uncertainties in the mean model parameters and correlations between the model parameters. It has been observed that these correlations follow the physics associated with the problem.

JOINT INVERSION OF DEEP SEISMIC SOUNDING (DSS) AND GRAVITY DATA: METHOD AND SOME RESULTS

V.I.Starostenko and V.G.Kozlenko
Institute of Gephysics, Nat. Acad. Sci, Pr. Palladin 32, Kiev 252680, Ukraine

Setting of the problem. Given: co-ordinates of the sources of oscillations and travel-time curves of observed seismic waves along the profile, observed gravity data, a priori information on the correlation relation between P-wave velocity and density.
Required: to construct such integrated velocity and density models, whose calculated wave and gravity fields correspond in some approximation to observed fields.
General scheme of solving the problem and its applications. The solution of the problem is the result of the successive realisation of a set of steps, which provide the basis of the velocity model for the study medium and then the construction of its density equivalent. If the obtained velocity-density model does not agree with the observed gravity field (within the limits of necessary error) or does not correspond to available geological information, then solving the problem is repeated in part by taking into account the results of the preceding step.
Developed: (1) algorithms for solving direct and inverse kinematic seismic problems in heterogeneous layered media; (2) algorithms for solving direct and inverse linear gravity problems; (3) a convenient stable method for solving of the system of linear equations, to which inverse seismic and gravity problems are reduced.
Testing of method and its practical application. We demonstrate the following results: (1) testing of technique for solving the inverse kinematic seismic problem on the example of test "California"; (2) solving of practical problems in regions related to the main types of geological environment

HOW TO MINIMIZE AMBIGUITY OF 3D TEMPERATURE ESTIMATES IN REGIONS OF RECENT VOLCANIC ACTIVITY?

Stephan Sobolev (EOST, Strasbourg, stephan@sismo.u-strasbg.fr)

3D temperature fields are usually calculated from surface heat flow using steady-state approximation. However this approximation fails in the regions of recent tectonic or volcanic activity. Additional difficulty is that some key parameters, like radiogenic heat production in the crust, are poorly constrained. Both factors introduce strong ambiguity in temperature estimates. I suggest to employ equilibrium pressure-temperature (P-T) estimates from mantle xenoliths and velocity perturbations from teleseismic tomographic model as additional constraints for temperature inversion. P-T estimates from xenoliths serve to estimate temperatures directly below xenoliths localities. Extrapolation of temperature field in 3D is done using both seismic velocity perturbations and surface heat flow (latter only in regions with relatively cold and seismically fast mantle). Seismic velocities are converted to temperatures considering effects of anelasticity and mineral reactions. The application of the technique for the French Massif Central will be presented which provide 3D temperature field in the mantle consistent with large variety of geophysical and petrological observations.

THE CORRELATIONAL VARIATIONAL PRINCIPLE IN THE PROBLEM OF INTEGRATED INTERPRETATION OF GRAVITIONAL AND SEISMIC DATA.

Strakhov V.N. (United Institute of Physics of the Earth, 123810, B. Gruzinskaja,10, Moscow,Russia)
Stepanova I.E. (United Institute of Physics of the Earth, 123810, B. Gruzinskaja,10, Moscow,Russia)

The interpretation of seismic and gravitational data on investigating the crustal and upper mantle structure is usually performed on the base of using an a priori given functional correlation between velocity and density of longitudinal seismic waves. The model of flat,two-dimensional gravitational field is used ordinarily thereby. In the most perfect versions of this approach the functional correlation includes parameters determined in the experiment. However,this approach seems to be too " strict"- tht means,there is no possibility to find out the zonac of violation of the correlation function. The authors of this paper have worked out a new approach to joint interpretation of gravimetric data based on the new variational principle. This principle consists in solving the problem of minimization of the correlation functional, depending on the velocity and density distributions in the given space domain (usually in the subhorizontal layer). It is assumed,that the zeroth-order approximation of the density is given and the difference between given density and observed one is to be determined. The solving of the formulated variational problem is reduced to the solving of a linear algebraic equations system. It is assumed,that the upper and lower limits of the errors in experimental data (the right-hand side of the system) are known. The problem of finding a stable approximate solution of the linear system described above is set up. A special algorithm to solve this problem has been designed. The so-called "test - solutions" are determined, such that the misfit between left-hand side of the linear system and experimental is equal to the upper limit of errors. Then the mean of these solutions is found. The proposed approach has been applied on solving several test problems.

EXPERIENCES WITH A DETAILED ESTIMATION OF THE MASS DENSITY CONTRASTS AND OF THE REGIONAL GRAVITY FIELD USING GEOMETRICAL INFORMATION FROM SEISMOGRAMS

G. Strykowski (National Survey and Cadastre, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark)

Abstract: In joint gravimetric-seismic modelling the fundamental problem is the lack of information which can help to reduce the inherent ambiguity of the inverse geophysical problems. The surface gravity signal reflects the true mass density contrasts in the shallow subsurface as well as the regional gravity response from the compensating masses.

In conventional inverse gravimetric method these density contrasts are assumed. Such assumption constrains the geometry of a body that generates the associated gravity signal. If the independent depth information in a local area is sparse, e.g. only few boreholes exists, the possible misfit between the obtained model and the direct depth information can be removed by an appropriate regional/residual separation of the gravity field. Thus, the unknown gravity signal from the compensating masses can be used to hide the consequences of wrong assumptions of the density contrasts.

The above practise of "just assuming" a mass density contrast is not satisfactory. The estimated geometrical parameters depend crucially on this value, and we cannot rely on the obtained model. This problem becomes particularly evident if the gravity data are used as "interpolator" between seismic lines or as "extrapolator" away from these lines. In a "real world" situation, where there are many contrasting layers with changing density contrasts in different depths, it is difficult to ensure the consistency between all the involved data by just assuming the density contrasts.

In this contribution, some experiences with the practical joint gravimetric-seismic modelling are discussed. In particular, it is demonstrated, how the depth information from seismics can be used to set up a system of equations, which can be used to estimate the density contrast between many geological layers (different contrasts in different depths). Thus, the geometrical information is used to estimate (i.e. as oppose to assume) the mass density contrasts. Furthermore the same system of equations can be used to estimate the regional gravity field associated with the compensating masses.

STRATIFIED GRAVITY IMAGE AND ITS APPLICATION -- THE TEST AND COMBINED APPLICATION OF SEISMIC TOMOGRAPHY

Qian-shen Wang (Institute of Geophysics,Chinese Academy of Sciences, Beijing 100101, China)

It is highly needed to develop an effective method to test the reliability of the 3-D stratified velocity structure of the earth's crust and upper mantle obtained by using the seismic tomography (ST) and to make full use of the ST results. In this paper, a new method named stratified gravity image (SGI) is presented. SGI is based on the theory of gravity and data of seismology. The density structure of each layer in the internal media of the earth can be obtained by means of the transformation relation of velocity - density correlation using the velocity structure of ST results. The images of gravity anomaly of each layer of various depths and the superposition of different layers can be obtained by calculating the gravity effect of the density model. In this paper, the chinese continent is choiced, as an example of application of SGI. The images of gravity anomaly of each layer and total gravity anomaly of 7 layers in China and adjacent area are obtained. By comparing the total gravity anomaly with the Bouguer gravity anomaly, the result shows hat the features of both gravity fields are quite conform, i.e., the result of SGI reflects fairly the distribution of the internal media of the earth. This method provided a new idea and possible way to solve the difficulty problem on the stratified analysis of interior structure of the earth by gravity method and data.

JOINT INVERSION OF GRAVIMETRIC AND TELESEISMIC DELAY TIME DATA

H. Zeyen (Institutionen för Geofysik, Uppsala Universitet, Villavägen 16, S-75236 Uppsala, Sweden)
U. Achauer (EOST, Université Louis Pasteur, 5, rue René Descartes, F-67084 Strasbourg, France)

Teleseismic delay time inversion has generally low resolution in the crust, where the largest velocity differences are observed, leading to errors in mantle velocity determination. Empirically, a roughly linear relationship between velocity- and density-variations has been found. If such a relationship exists, joint inversion of delay time and gravimetric data can be used to reduce inversion errors in the crust. With this reasoning in mind, we have developed an algorithm to invert jointly gravimetric Bouguer anomalies and teleseismic delay times, based on a Bayesian approach. Parameters to be inverted are velocity and density variations in blocks of horizontal layers as well as a common correlation factor between velocity and density variations for all blocks of one layer. The correlation factor is allowed to vary between layers. Within each layer scattering around a velocity-density correlation is allowed. Stabilisation of the inversion process is achieved by adding terms for smoothness and a priori information. In our talk we will present the algorithm and its application to synthetic as well as real data obtained in Kenya. The results of the joint inversion will be compared to pure velocity inversion (ACH-method), highlighting the advantages in case of an existing velocity-density correlation and demonstrating the behaviour in more problematic situations, where the correlation is disturbed.

A PRIORI INFORMATION IN INVERSE PROBLEMS OF ATMOSPHERIC OPTICS

Yu. M. Timofeyev (Research Institute of Physics at St.Petersburg State University, Ulyanovskaya 1, St.Petersburg-Petrodvorets, 198904 Russia)

A great variety of atmospheric and surface characteristics is obtainable from the measurements of different characteristics of electromagnetic radiation (spectral, angular, polarization, temporal and spatial). Because the inverse problems of atmospheric optics are ill-posed, a considerable amount of a priori information is used to solve them. It may be the insights on quantitative or qualitative characteristics of interaction between the radiation and medium, the assumptions on the medium state or definite constraints on the solution, the numerical models of the processes in "atmosphere - surface" system, etc. Common classification of a priori information used and methods of prescribing it are given. Various inverse problems of atmospheric optics are inspected for a priori information used, strengths and weaknesses of different approaches, influence of a priori information amount on the inverse problem solution are analyzed. Particular emphasis has been placed on the importance of atmospheric radiation models and the use of radiation measurements in different spectral ranges in solving the inverse problems.

JOINT INVERSION OF ELECTRIC AND ELECTROMAGNETIC DATA

P. Weidelt (Institut für Geophysik und Meteorologie, Mendelssohnstr. 3, D-38106 Braunschweig, Germany)

In an Earth with a layered electrical conductivity structure, the different methods of electric and electromagnetic prospecting give rise to very different current systems: In the electric (DC) methods, using an impressed current, adjacent layers are coupled *galvanically* by the vertical component of the current density, whereas in the electromagnetic methods, where the induced current flow in the ground is horizontal (irrespective of the source), adjacent layers are coupled *inductively* and therefore - in contrast to the electric methods - the electromagnetic field can penetrate beyond resistive layers. Therefore in electric data poorly conducting regions (forming sensitive barriers) are highly weighted, whereas electromagnetic methods are insensitive to these regions, but impose much weight on good conductors below them. - Merging electric and electromagnetic data will result in an overall increase of resolution. After examining the theoretical basis of this assertion, we demonstrate the increase of resolving power by a number of field examples. A problematic feature of these experiments is that best agreement is often attained using an *anisotropic* conductivity model.

EGS2 Modelling techniques in geology and geophysics by the aid of Geoscientific Information Systems (GIS)

Convener: Götze, H.-J.
Co-Conveners: Burger, H.; Schmidt, S.

MODELLING OF SALT DOMES FROM SCATTERED NON-REGULAR POINT SETS

Roberto Lattuada Birkbeck College, London
Jonathan Raper Birkbeck College, London

The modelling of salt domes and other bodies with similar features often requires the construction of a compact 3D representation from scattered sets of seismic data. These datasets provide only partial information about the unknown volume. A solution is proposed that is based on the representation of an object as the union of simple volume primitives (tetrahedra). Three dimensional triangulation methods are used to generate a valid model and to provide geometrical and topological attributes for the scattered samples set. This generates an exact fit and unambiguous 3D model which can be evaluated using a 3D spatial query language.

PROCESSES INFLUENCED ROCK PROPERTIES IN EARLY PALEOZOIC SEDIMENTARY BASIN IN ESTONIA

L. Bityukova and A. Shogenova (Institute of Geology, 7 Estonia Avenue, Tallinn EE0001, Estonia, e-mail: alla@gi.ee)
H.-J. Götze (Institut für Geologie, Geophysik und Geoinformatik, Freie Universität Berlin, Malterstr. 74-100, 12249 Berlin, Germany

Sedimentation and secondary alteration processes were studied in the different structural zones of Ordovician and Silurian basins. Late diagenetic alterations of rocks in stratigraphic layers and in fracture zones influence their structure, mineral and chemical composition and physical properties. The rock properties of 780 carbonate samples of different age and genesis were studied using geochemical and petrophysical data (25 parameters). Isomorphous substitution of Mg by Fe and Mn in the crystal lattice of dolomite during metasomatic dolomitization is the most remarkable process influenced magnetic properties and grain density of lower and middle Ordovician rocks. Sedimentation processes determined the clay content in the upper Ordovician and Silurian rocks control the most of their petrophysical properties.
This work has been supported by Volkswagen Foundation under grant Ref. No.: I/70 410.

A GENERIC SYSTEM FOR INTEGRATED MODELLING OF MULTI-DIMENSIONAL SPATIAL DATA

Iain M.Brown (University of Glamorgan, Wales, UK)

This paper describes how a generic 3D visualisation system (AVS) can be further developed and customised to meet the unique demands of modelling earth science data. The advantages of this approach include its flexibility and ability to handle a wide variety of different data types. For instance, it allows the integration of geoscience data-sets together with reference maps from a conventional GIS (eg. ARC/INFO). The system also allows geophysical data, expressed in the form of continuous fields, to be modelled in the same environment as other geological data. We can also query spatial attributes for further information, and estimates of data reliabilty (obtained via geostatistics) can be graphically portrayed on the final display.
Experience with a wide range of models has emphasised the importance of knowledge in the modelling process. In many cases, the sparse nature of sampling means that interpolation methods using techniques such as iso-surfaces and slicing allow a clearer picture of 3D objects than direct volume rendering techniques, unlike in other scientific disciplines. These principles have been extended to 4D data-sets by incorporating time-slices into animation. We have also converted the output from some of the models into VRML format. This has become the de facto standard for 3D viewing and interaction across the Internet and provides scope for establishing collaborative environments for future research.

SPATIAL AND TEMPORAL REASONING TECHNIQUES IN GEOLOGICAL MODELLING

C. Chiaruttini (DINMA, University of Trieste, I-34127 Trieste, Italy)
V. Roberto and M. Buso (Department of Informatics, University of Udine, I-33100 Udine, Italy)

In building geological models of the subsurface, spatial and temporal consistency is a necessary condition for correct data interpretation.
We analyse the spatial and temporal knowledge involved in geological modelling, and propose a mathematical model of sedimentary bodies, which captures some of the basic principles of sequence stratigraphy. In this way, spatial and temporal relations among sedimentary units can be formally described, and constraints to be satisfied by the correct models can be exactly stated. The model is a qualitative one and is based on topology and graph theory. In this framework, we designed a set of algorithms aimed at:
1) Helping the user in focusing attention on the most relevant structural elements, like markers, pinch-outs and depositional units;
2) Validating the spatial and temporal consistency of model hypotheses;
3) Diagnosing inconsistencies.
The validity of our approach as been tested with an application to the construction of subsurface models from seismic reflection survey data.
This work is part of the *Horizons* research project aimed at the construction of an advanced workstation for seismic interpretation.

HOW TO VISUALISE THE PROPAGATION OF A SHALLOW SEISMIC RUPTURE ? A 2D VIEW COMBINING ANISOTROPIC WAVELET TRANSFORM AND GIS

J. Darrozes, P. Gaillot, N. Angenieux and P. Courjault-Radé (UMR 5563 - CNRS 38, rue des 36 Ponts F-31400 Toulouse)

Rupture propagation of moderate and shallow (h < 5-6 km) earthquakes integrates a number of interactions with the highly fractured uppermost crust. Its study requires accurate superposition of different set of data, namely the seismic data, the geological and geomorphological data. The numerous aftershocks necessary to identify the rupture planes, require an objective data processing method which, in particular, allows to detect linear distributions and clustering of the aftershocks. We present images of the evolution of rupture propagation, performed by combination of GIS and of a new powerful data processing, the NOAWC method (Darrozes and al., submitted). The NOAWC method is based on the Anisotropic Wavelet Transform formalism and applied to detection of multi-scale structures. Our example depicts the rupture propagation along a horse-tail termination of a main dextral strike-slip fault, connected with the M=5.1 Arudy earthquake (80/29/02), located in the French Western Pyrenees.

THE INFLUENCE OF THE EARTH'S GRAVITATIONAL ANOMALY BOUNDARY EFFECTS UPON THE LANDSCAPE ELEMENTS

E.Z.Gak (The Agrophysical Research Institute, 14, Grazhdanskii Prospect, 195220, Saint-Petersburg, Russia)
V.I.Gridin (Russian Academy of Science, The Institute of Oil & Gas, 63/2, Leninskii Pr., GSP-1, 117917, Moscow, Russia). A.E.Smolyar (Academy of Civil Aviation, 38, Ulitsa Pilotov, 1962106 Saint-Petersburg, Russia)

The results, obtained by the present time after experimental and test-series field investigations as well as their respective processing in combination with the materials of remote exploring show that the deep-seated structures that form the gravitational field anomalies define not only the nature of the agrotopography, the composition and the type of the soil cover changes but the kind of movement of the underground waters too. The work shows that in the origin of such phenomena much depends upon the availability of the tangential component of the gravitational anomaly $\Delta \bar{g}_t$ characterised not only by the availability of natural slopes of the terrain but also by depth effects. There have been analysed the causes and the conditions of the origin of the $\Delta \bar{g}_t \neq 0$ and the importance of gravitational anomalies in the processes of transfer of mass, heat and humidity. The results that have been obtained allow to state that in the zones of the gravitational anomalies there also occur anomalies of other physical fields (electric, magnetic, radiation), which, in its turn, affect also the elements of the terrain. The results thus obtained may be applied for solving a number of problems encountered in geophysics, agriculture, ecology, hydrophysics and others.

GEOLOGICAL REFINEMENT OF THE EUROPEAN GEOID

G. Gerstbach and T. Tengler (Institute of Geodesy and Geophysics, TU Vienna, Gusshausstr. 27-29/128, A-1040 Wien, Österreich.

Modern geoid solutions aim to accuracies of a few centimeters, but need very narrow point spacings (gravimetry 1-3km, astropoints 5-10km). This problem can be defused by additional geological data: the errors are reduced to at least 50% (or the number of points to a quarter or less) which is shown by GIS programs.

The most important geological informations are the rock density of the local topography and the inclination and density of subsurface layers. Relevant densities (1.8 ...3g/cm³) differ often very much from the standard value 2.67, but can be derived roughly from outline geological maps. Such maps (scales 1:100.000-1:1million) are existing anywhere in developed countries.

Geoid projects in Austria and Switzerland show improvements of 15-40% using *surface* densities. To get *subsurface* data the effort is greater but also the effect, esp. in sediment basins and tectonic areas (many of the plains, most parts of alpine regions). Gravity is sensitive to subsurface mass anomalies, vertical deflection to layer inclinations. Because the latter can be estimated better than the densities itself, the geological improvement of astrogeoids is more effective than of gravimetric geoids.

In many tectonic areas *detailed* density models can be derived from drilling data and geological profiles. Gravimetry needs full 3D geology, astrogeoids only 2.5D (inclination). Improvements up to 70% are possible. South and East Europe should make use of the above benefits: vertical deflection data are quite dense, and geological surveys have sufficient quality. Even by rough geological maps or profiles the geoid can be improved to a few cm/100km (locally 1-2cm) within 10 years.

INTEGRATION OF CONSTRAINING DATA AND POTENTIAL FIELD MODELLING

H.-J. Götze and S. Schmidt
Fachrichtung Geophysik, Freie Universität Berlin, D-12249 Berlin

Three-dimensional (3-D) interactive geophysical modelling permits integrated processing and interpretation of potential field data, yielding an improved geologic interpretation. Generally 3-D models are constructed by triangulated polyhedra and constant density and/or induced and remanent susceptibility. Interactive modification of model parameters (geometry, density, susceptibility) access to the numerical modelling process and direct visualization of both, calculated and measured fields of gravity and magnetics. This enables the interpreter to design the model as realistic as possible ('Trial and error' method).

The effect on gravity and magnetic field of a homogeneous polyhedron is calculated by transforming the volume integral into a sum of line integrals. The basic methodology was modified and optimized most recently.

GIS information is used to constrain the wide range of theoretically equivalent solutions.

IVIS-3D: A TOOL FOR INTERACTIVE 3D-VISUALIZATION OF GRAVITY MODELS, BASED ON VTK AND XFORMS

Dr. Christian Klesper (Inst. f. Geologie, Geophysik u. Geoinformatik
Freie Universität Berlin, GERMANY)

In the case of 3D-visualization and analysis of complex geoscience models, existing modeling systems can meet the user requirements only inadequately. Either a lack of functionality is compensated with a patchwork of different programs or the user has to handle complex systems with a large overhead of functionality. For this reason we decided to create IVIS-3D (IGMAS **Vis**ualization in **3D**). IVIS-3D is a interactive 3D-visualization tool, which is specially adapted to our requirements and the modeling process of our gravity/magnetic modeling system IGMAS.

The graphical front-end is based on the public domain VTK-library, which is an object oriented approach in C++, using GL, OpenGL or MESA. The graphical user interface is realized with the X-window based and public domain GUI-builder XFORMS. Therefor the tool is independent of the graphical kernel and running on all UNIX and LINUX workstations. With a minimum of functionality IVIS-3D now gives us the capability to render and analyze IGAMS models in three dimensions.

www: http://userpage.fu-berlin.de/~wwwgravi/Welcome_e.html
e-mail: geochris@fub46.zedat.fu-berlin.de

IVIS-3D: AN INTERACTIVE 3D VISUALIZATION TOOL FOR IGMAS

Dr. Christian Klesper (Inst. f. Geologie, Geophysik u. Geoinformatik
Freie Universität Berlin, GERMANY)

We created a new interactive 3D visualization tool based on public domain software. IVIS-3D (IGMAS **Vis**ualization in **3D**) can be used as an optional application to support the modeling process and the analyses of 3D-gravity models, created with IGMAS. It has the capability to render interactively 3D-geostructures and to change various attributes in a simple way. The graphical front-end is based on the public domain VTK-library, where the user interface is realized with the GUI-builder XFORMS.

IVIS-3D is specially adapted to our requirements and the modeling process of IGMAS and fulfills the following points:

- it handles all IGMAS objects and renders their topology and attributes
- it can be used in a standalone mode as well as an optional tool of IGMAS
- it´s independent of the graphical kernel, running under UNIX and LINUX
- the GUI is simple to use and it´s freed of any application overhead
- it supports the frequently used 3D visualization features

www: http://userpage.fu-berlin.de/~wwwgravi/Welcome_e.html
e-mail: geochris@fub46.zedat.fu-berlin.de

REPRESENTING THE GRAVITY RESEARCH GROUP ON THE WEB

Dr. Christian Klesper & Prof. Hans-Jürgen Götze (Inst. f. Geologie, Geophysik u. Geoinformatik, Freie Universität Berlin, GERMANY)

In the past 3 years the World Wide Web (WWW) has become an international accepted media for any kind of presentation with more than 30 million potential customers. This enormous information and the easy access to it makes the Web to one of the most interesting medias for university research. Researchers are publishing their works on the Web and using it for database queries as well as a new communication base for international and interdisciplinary research.

Also our research group uses this media to represent it´s work and to perform an open base for international discussions. With the new capabilities of JAVA, VMRL, and HTML3 the following points are some interesting new features planed for our Web-pages:

- online access to databases and GIS of our institute
- online demos of our modeling programs
- interactive visualization of 3D-gravity models

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e-mail: geochris@fub46.zedat.fu-berlin.de

1D AND 2D MODELLING OF THE BURIAL HISTORY OF THE EAST-BARENTS SEA BASIN.

Maxim V. Korotaev (Moscow State University, Moscow, Russia;)
Sierd Cloetingh (Vrije Universiteit, Amsterdam, The Netherlands)
Anatoly M. Nikishin (Moscow State University, Moscow, Russia;)
Edward V. Shipilov (Institute for Marine Geophysics, Murmansk, Russia)

Tectonic history of the East-Barents Sea basin was reconstructed using data of 1-D and 2-D burial history modelling.

Main rapid subsidence events took place in the eastern Barents Sea region in the Early Ordovician, Early Devonian, Late Devonian, Late Permian-Early Triassic, Late Jurassic-Easrly Cretaceous. Burial history modelling and regional geological data show that main rift phase with the East-Barents Sea deep-water trough origin took place during the Late Devonian. Since the Permian times the basin was a foreland area of the Ural-Pay-Khoy-Novaya Zemlya Orogen with a huge clastic sedimentation.

A proposed tensional event took place at the Permian/Triassic boundary. Compressional tectonics was in the Late Triassic with foredeep basin origin in front of Novaya Zemlya Orogen and syncompressional uplift of the Central Barents Sea High. Weak tension event took place at the Jurassic/Cretaceous boundary.

VOLUME MODELLING OF GEOLOGICAL MATERIALS

R. Marschallinger (Inst.f.Geologie, Hellbrunnerstr.34, A-5020 Salzburg)

Handling geological materials by means of a volume modelling system enables quantification, spatial analysis and state of the art visualization and communication of complex spatial relations in minerals and rocks. Despite these obvious advantages, 3-D modelling of micro- and macrostructures is rarely applied in geosciences. An efficient and versatile method has been established which is capable of integrating 3-D modelling of discrete spatial variation (e.g. mineral phase boundaries, cracks) as well as continuous spatial variation (e.g. chemical zonations, color zonations) in geological materials. The method is based on a cycle of precision serial lapping and subsequent data acquisition by scanning the newly eroded sample surfaces. The range of physical dimensions of features to be modelled is some microns up to some centimeters. The type of raster acquisition device used merely depends on size and character of features to be reconstructed (e.g. a color flatbed scanner for macrostructures, a scanning microscope or a scanning microprobe for microstructures). Scanned data are subject to image calibration (continuous spatial variation) or image classification (when modeling discrete features). Processed images are transferred into a voxel array for geometrical correction and, if necessary, 3-D interpolation. The resulting 3-D models can be viewed from any direction, sliced and peeled, classes of features can be merged, extracted, be made transparent or inivisible and physical parameters like distances, directions, surfaces and volumes can be computed.

MAFIC DYKE SWARMS IN EASTERN FENNOSKANDIAN SHIELD - FINNISH MAFIC DYKE GIS-DATABASE

Salmirinne, H., Institute of Geosciences and Astronomy, Univ. of Oulu, Finland
Vuollo, J., Institute of Geosciences and Astronomy, Univ. of Oulu, Finland

Work on the project "Palaeoproterozoic basic igneous activity in the eastern Fennoscandian Shield and correlation with the North Atlantic Area", is taking place at the Institute of Geosciences and Astronomy in the University of Oulu. The aim is to obtain a clear picture of the areal and temporal distribution of mafic dyke swarms, their geochemical characteristics, geophysical properties, geochronology and relationship to ore critical magmatic events. The Archaean basement and its palaeoproterozoic cover in the eastern and northern Fennoscandian Shield are dissected by thousand of palaeoproterozoic mafic dykes and sills. All available data on dyke swarms will be gathered into a GIS-system to help combine and correlate the information. The poster will prese nt an updated global dyke map for part of the eastern Fennoscandian Shield (Finland and some areas in Russian Karelia and the Kola Peninsula). The original database was obtained from Ottawa, Canada under the "Global mafic dyke GIS-database project" funded by LITHOPROBE Canada, and has been updated in some respects at the University of Oulu. Detailed regional maps of the Romuvaara and Veitsivaara areas in the eastern part of Finland showing the distribution and characteristics of dyke swarms will also be p resented. In both areas diabase dykes (2.45 - 1.98 Ga) intersecting Archaean rocks represent the youngest elements in the bedrock.

SMOOTHING OF 2*D* AND 3*D* DATA BY USING SPLINES WHICH ARE PIECEWISE BIHARMONIC FUNCTIONS

O. Kounchev and **O. Kounchev** (Permanent: Institute of Mathematics, Bulgarian Academy of Sciences, Sofia, Bulgaria; Visiting: Department of Mathematics, University of Duisburg, 47048 Duisburg, Germany)
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There exist different approaches towards modelling and approximating multivariate (in particular, scattered) data. The usual approaches like *Polynomial Splines, Krigging and Radial Basis* have difficulties when working with data that are not equally spaced - either their implementation is very hard, or the results obtained are very unrealistic. They are also not easy to implement on surfaces, even in the simplest case of the sphere.

We propose an approach which uses piecewise solutions of elliptic equations (more specially, biharmonic functions) instead. We call these generalized multivariate splines *polysplines*. The polysplines are rather flexible and permit arbitrary geometry of the controlling points and are possible to implement on bodies with a simpler geometry like the sphere, ellipsoid, etc.

Our approach has proved to be *very effective* in smoothing data arising from *potential fields*. We present a case study of aeromagnetic data which have been collected over 15 tracks (profiles). We provide a comparative study with others methods, e.g. krigging. It shows that the smoothing obtained by using the polysplines is more realistic than the smoothing obtained by the competitive methods.

The effectiveness in smoothing potential field data is based perhaps on the fact that the biharmonic functions are themselves intimately connected with the harmonic functions, and are expressible through them by the Almansi formula.

CONSTRAINTS ON CASCADIA SUBDUCTION FROM CONTRASTING MODELS OF CRUSTAL AND MANTLE DENSITIES

T.V.Romanyuk (IPE, B.Gruzinskaya 10, Moscow, 123 810, Russia)
R.J.Blakely and W.D.Mooney (USGS, 345 Middlefield Rd, MS 989, Menlo Park, CA 94025, USA)

The style of subduction of the Juan de Fuca plate beneath North America changes markedly along the length of the subduction zone, especially in the angle of subduction, distribution of earthquakes, geologic and seismic structure of the upper plate, and regional horizontal stress. To investigate density characteristics, we conducted detailed modeling experiments of the crust and mantle along two transects across the Cascadia subduction zone, one across Vancouver Island and the Canadian margin, the other across the Oregon margin of the United States. Models of crustal and mantle density were produced with a 2-D linear gravity inversion technique. This technique approximates the crust-mantle cross section by a set of blocks based on published seismic refraction models. Each block is allowed to have a range of densities, constrained where possible by borehole measurements and seismic velocities. To further constrain the models, we assumed that oceanic crust has the same density-depth ratio at both transects and that the lithosphere is in isostatic equilibrium in the deep ocean and east of the modern volcanic arc. Our results confirm that the downgoing slab beneath Vancouver Island dips significantly gentler than at Oregon, supporting the idea that the Juan de Fuca plate is segmented from north to south. The Oregon segment has an anomalous block within the mantle situated between the continental crust and the subducting Juan de Fuca plate. This block is located beneath the aseismic Western Cascades and is characterized by a density lower than the mantle density beneath the modern volcanic arc in both segments. This reduced density agrees with observed lower mantle velocities, extensional geodynamic regime, and other characteristics of the Oregon margin.

INTERACTIVE VISUALISATION AND MODIFICATION OF DENSITY AND/OR SUSCEPTIBILITY MODELS USING GIS FUNCTIONS

S. Schmidt and H.-J. Götze
Fachrichtung Geophysik, Freie Universität Berlin, D-12249 Berlin

The problem of forward and backward modelling of potential field data, which deal with quantitative modelling, is the integration of information constraining the large number of possible solutions. This information - data in a geophysical sense - is different in nature and origin in most cases: inhomogeneous and unevenly distributed, in many cases uncertain, especially if they describe human knowledge.

An approach is described to integrate these data into the interactive modelling process by means of visualizing and combining constraining data with the density/susceptibility model. This visual combination of different 2- and 3-D models enables a quantitative comparision and adjustment, and results in a model comprising as much independently derived information as possible. The definition of 'geo-objects', which link geoscientific vocabulary with geometrical elements of the density model, provides a comfort environment for interpretational discussions in front of the computer monitor.

TECHNIQUE OF COMPLEX ANALYSIS FOR STUDY PROCESSES IN SEDIMENTARY BASIN STRUCTURES (IN ESTONIA)

A. Shogenova and L. Bityukova (Institute of Geology, 7 Estonia Avenue, Tallinn EE0001, Estonia, e-mail: alla@gi.ee)
H.-J. Götze (Institut für Geologie, Geophysik und Geoinformatik, Freie Universität Berlin, Malterstr. 74-100, 12249 Berlin, Germany

25 petrophysical and geochemical parameters of 780 Ordovician and Silurian rock samples from 6 outcrops and 18 boreholes were studied together with logging data, geological and stratigraphic information. 11 magnetic, electrical, density and seismic variables were investigated together with 14 chemical parameters including 2 iron forms. Correlation and R-mode factor analysis were used to reveal the most important processes in the early Paleozoic sedimentary basin. Interpretation of processes were made taking into account the highest loadings on the geoche-mical parameters. The sections of fracture zones were plotted in contours of studied parameters using Kriging algorithm. Clay content and dolomitization process were established the most important for physical parameters.

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3-D MODELLING TEGHNIQUES IN GRAVITY OF HETEROGENEOUS MEDIA

V.I.Starostenko, **O.V.Legostaeva**, A.N. Zavorot'ko, T.P.Yegorova
Institute of Gephysics, Nat. Acad. Sci, Pr. Palladin 32, Kiev 252680, Ukraine

An automated system is developed for the study of 3-D layered media, which is a tool for modelling of oil and gas bearing sedimentary basins.
The setting of a problem. Initial data (relief of top and bottom of the layer, density distribution on these surfaces and so on) in the form of maps are input to the system. In the output of the system the maps of the calculated parameters (gravity effect etc.) are obtained. All procedures are carried out automatically. All information is taken from a geological data bank.
The structure of the system. The software developed consists of three main blocks of programs: (1) input of maps to the computer and creating its digital model; (2) solving of direct and inverse gravity problems for aggregate of 3-D heterogeneous bodies approximating the layer. In the capacity of there elementary bodies we use a rectangular vertical prism with arbitrarily located upper and lower faces and with heterogeneous density with given values in the prism apexes and density changes according to linear or exponential functions inside prism; (3) presentation of the results in the form of maps.
Application of the system. The system relieves the geophysicist of routine hand work and permits the rapid and efficient study of the structure of oil and gas provinces during all stages of geological prospecting. In addition it may be used for the study of large-scale geological and geophysical problems.

EGS3 Tectonic and integrated geophysical studies of the continental lithosphere

Convener: Kissling, E.
Co-Conveners: Banda, E.; Thybo, H.

Sponsorship: EUG

SPACE/TIME-MODELLING OF THE LOWER RHINE BASIN SUPPORTED BY AN OBJECT-ORIE NTED DATABASE

Agemar Siehl, Rainer Alms, Tobias Jentzsch (Geological Institute, Bonn University, D-53115 Germany)
Armin B. Cremers, Oleg Balovnev, Martin Breunig (Institute of Computer Science III, Bonn University, D-53117 Germany)

In the framework of the Collaborative Research Center "Interactions between and modelling of continental geo-processes" at Bonn University, a joint 3D/4D GIS is developed by geologists and computer scientists. When analyzing and modeling the structural and sedimentary evolution of the Cenozoic intracratonic Lower Rhine Basin in NW Germany, the need emerged to combine methods and tools of space-time modeling of geologically defined geometries with advanced database management techniques. Computer aided geological design typically requires operations of storage, retrieval and handling of large 3D data sets with their attributes and topological relations for the generation of model surfaces of stratigraphic boundaries and faults, which in turn define the boundaries of geological bodies developing in time. The requirements of interactive visualization, analysis and modification of such complex and time-dependent geometries entail the demand for spatial, topological and time-related database queries as well as for various consistency and integrity tests. Considering these specific geological requirements, an object oriented geo-database kernel system has been designed and implemented as a "GeoToolKit" for 3D/4D geoscience applications.

SEISMIC TERRANE CHARACTERISTICS OF BALTICA AND E. AVALONIA IN THE SOUTHEASTERN NORTH SEA

Tanni Abramovitz, Hans Thybo and MONA LISA Working Group
Geological Institute, University of Copenhagen
Øster Voldgade 10, DK-1350 Copenhagen K, Denmark

The velocity structure of the crust and uppermost mantle along the N-S trending MONA LISA lines 1 and 2 has been modelled from coincident wide-angle and normal-incidence seismic data. The velocity models are similar along the two subparallel profiles which are 50-100 km apart. They image three different crustal types: a three-layered shield type Baltica crust to the north; a highly complex transitional crust in the central part; and a two-layered crust of Caledonian origin to the south. The lower crustal velocities are 6.9-7.2 km/s in Baltica and only 6.0-6.3 km/s in Avalonia. S-dipping crustal reflections from 4-11 s twt are interpreted as the Caledonian suture. It downlaps onto the Moho in a 50-70 km wide lenticular zone of increased lower crustal reflectivity with velocities of 6.7-6.9 km/s. We interpret this zone as a remnant of oceanic crust or island arc, which was accreted onto Baltica during N-ward subduction of the Tornquist Sea. Sub-Moho velocities are 7.8 km/s under the 40-35 km thick Baltica crust and 8.3 km/s under 27-25 km thick Caledonian crust. The sub-horizontal Moho across the collision zone implies late- or post-Caledonian re-equilibration of the Moho. Former Baltica lower crust was subdued as a result of lithospheric flexure during the Caledonian orogeny. We suggest that pressure induced metamorphism transformed these lower crustal rocks into eclogite facies which today appear as upper mantle. The present Moho is thus the result of a progressive Moho that was uplifted to its present position during the Middle Devonian collapse of the North German-Polish Caledonides.

AGE-DEPENDENT LARGE SCALE FABRIC OF THE MANTLE LITHOSPHERE AS DERIVED FROM SURFACE-WAVE VELOCITY ANISOTROPY

V. Babuska (UNESCO, Div. Earth. Sci.,1,rue Miollis, 75732 Paris, France, v.babuska@unesco.org)
J-P. Montagner and N. Girardin (I.P.G.P., Dept. de sismologie, 75252 Paris, France;jpm@ipgp.jussieu.fr,girardin@ipgp.jussieu.fr)
J. Plomerova (Geophysical Institute, Czech Acad. Sci., Bocni II, 141 31 Praha 4, Czech Republic, jpl@ig.cas.cz)

Systematic variations of the seismic radial anisotropy down to depths of 200-250km in North America and Eurasia and their surroundings are related to age of continental provinces, and typical depth dependences of a relative radial anisotropy are determined. The relative radial anisotropy in the mantle lithosphere of Phanerozoic orogenic belts is characterized by vSH>vSV, with its maximum at depth of about 70km. on the average, while beneath old shields and platforms, it exhibits a maximum deviation from ACY400 model (Montagner and Anderson, 1989) at depths of about 100km with vSV>=vSH signature. An interpretation of the observed seismic anisotropy by the preferred orientation of olivine crystals results in a model of the mantle lithosphere characterized by anisotropic structures plunging steeply beneath old shields and platforms, compared to less inclined anisotropies beneath Phanerozoic regions. This observation supports the idea derived from petrological and geochemical observations that a mode of continental lithosphere generation may have changed throughout Earth history.

A MULTIDISCIPLINARY STUDY IN THE BETIC CHAIN

V. Sallar'es, J.J. Da nobeitia and **R. Carbonell** (Dept. Geophysics, CSIC-Institute of Earth Sciences, (Jaume Almera), Llu'is Soler i Sabar'is s/n, 08028 Barcelona, Spain)
J. Pous, P. Queralt (Dept. de Geologia Din'amica, Geof'isica i Paleontologia, Univ. de Barcelona, Mart'i Franqu'es s/n, 08028 Barcelona, Spain.)

The analysis of three different geophysical datasets confirms that the Betics orogen consists of the juxtaposition of two crustal domains characterized by distinctive physical properties. At depth these datasets show evidence for a non- coincidence of the petrological and the seismic Moho beneath the Betics chain. These datasets reveal the geophysical properties of the Alboran Domain (Internal Betics) and the Iberian Massif (External Betics). According to this the Iberian Crust, features a relatively high seismic velocity, is seismically transparent in the seismic reflection images and is electrically resistive. The Alboran Domain crust is characterized by a low average velocity, displays high reflectivity in the seismic reflection images and is electrically conductive. The outcrops of the metamorphic complexes (Alpuj'arride and Nevado Fil'abride) show relatively high velocities coupled with low values for the Wadati slopes Vp/Vs of 1.67 revealing the existence of rocks rich in silica beneath the Alboran Domain crust. An interpreted detachment at 12 km depth images by the deep seismic reflection suggests that these rocks could be related to the Iberian Upper crust.

CAN THE CONTINENTAL LITHOSPHERE BE MODELLED AS AN ELASTIC PLATE?

S. C. Francis, R. Hipkin and R. Banks (Department of Geology and Geophysics, West Mains Road, Edinburgh. EH9 3JW. United Kingdom.)

Early studies of the linear transfer function (admittance) between gravity and topography yielded values for the effective elastic thickness of the continental lithosphere which are consistently smaller than those obtained from flexure studies, for example post-glacial rebound. This discrepancy was explained by Forsyth (1985), by including subsurface loads in the plate bending model. Different combinations of surface and subsurface loading can produce very different forms for the admittance, making interpretations ambiguous. Forsyth proposed an alternative method for determining elastic plate thicknesses using the coherence which is less sensitive to the depth of the load. The coherence method also tends to give elastic thickness values closer to those expected from flexure studies and has therefore since been widely used in place of the admittance. We have carried out a detailed study of both admittance and coherence to determine whether Forsyth's elastic plate model can generate a solution which is consistent with both. The Qattara Depression in Western Egypt is widely believed to have formed by karstification of a hard limestone cap followed by aeolian erosion of the softer underlying sediments. It therefore provides an excellent test example of a topographic load of non-tectonic origin with no associated subsurface loading. Preliminary results indicate that subsurface loading does not explain the discrepancy in elastic thickness estimates in this region: modifications to the elastic plate model are therefore required.

PROJECT INDEPTH: INTEGRATION OF GEOPHYSICS AND GEOLOGY IN THE EXPLORATION OF THE TIBET PLATEAU

L. Brown and Project INDEPTH Working Group (Chinese Academy of Geological Sciences- P.R. of China; Cornell, Syracuse, Stanford, and New Mexico State Universities, SUNY Albany, and University of Washington- U.S.; Kiel University, GFZ Potsdam- Germany; Geological Survey of Canada)

Project INDEPTH investigations in Tibet have included closely integrated controlled source and passive seismic recording, magnetotelluric (MT) sounding and geologic mapping of surface structure. Seismic reflection profiling (CMP) resulted in a new structural model for the crust beneath the Himalaya and discovered a series of mid-crustal "bright spots" attributable to magma beneath the southernmost Plateau. Simultaneous wide-angle (WA) recording of the CMP sources (explosives) provided estimates of bulk properties (P&S velocity, attenuation) as well as S wave confirmation of the fluid origin of the bright spots. In addition, the WA program also furnished important 3-D control on structural geometry and filled key gaps in CMP coverage. Collocated passive (broadband) recording contributed the most useful estimates of crustal thickness and revealed the presence of a low velocity zone beneath the bright spots. The magma interpretation of these combined seismic data was greatly strengthened by MT observations of very high conductivity in the middle and lower crust. The interpretation of low-angle extension from the seismic data was particularly dependent upon new surface mapping. Synthesis of these mutually reinforcing observations suggests extensive partial melting beneath the Tibet Plateau and lends strong new support to "hydrostatic" models of plateau uplift.

LITHOSPHERIC DEFLECTIONS BY SEDIMENT LOAD AND CRUSTAL THINNING, AND THE EFFECT OF INTRAPLATE STRESS IN THE NORTHERN VIKING GRABEN, OFFSHORE NORWAY.

W. Fjeldskaar (RF-Rogaland Research, P.O. Box 2503, 4004 Stavanger, Norway), H. Johansen (Geologica AS, P.O. Box 8043, 4003 Stavanger, Norway, P. Christiansson and J.I. Faleide (University of Oslo, Department of Geology, P.O.Box 1047 Blindern, N-0316 Oslo, Norway).

It has been shown that lithospheric extension may take place by simple shear in the upper lithosphere and by pure shear below a horisontal detachment in the lower lithosphere. The purpose of this study was to analyse and model basin dynamics and factors controlling formation of the Viking Graben, northern North Sea, and especially quantify the amount of thinning from simple shear by faulting and pure shear by McKenzie extension of the lower lithosphere. The cumulative thinning over the Viking Graben is up to maximum 2.5 for a flexure model with elastic thickness of 2km. To be able to explain the total subsidence in the Viking Graben a coupled model with extension taking place by simple shear in the upper lithosphere and pure shear extension below a horizontal detachment in the lower lithosphere seems to be necessary. There is observation indicating a significant compressional stress field in northern Atlantic today. The effect of intraplate stresses to a lithosphere containing the pre-existing deflection above has been modelled. For an elastic thickness of 2km and a stress of the order of 3 kbar, the stress-induced deflection could have an amplitude of 600m.

TECTONIC CONCENTRATORS-NEW TERM AND SENSE.

Vadim A.Galkin (119899 Geol.Dp.,MSU,VorobiovyHills, Moscow Russia)

The concentrators (Cn) of stresses are the main strain and rupture controlling factors in models of Structurized Medium Mechanics. In rocks the grain boundaries and intradefects play the roles of such obvious Cn. Visible or potential blocks boundaries or noncalculated previusly zones of their interaction may be also important. General feature of deormation is that the larger Cn affect the process in the first turn and live longer than small ones. These ideas may be applied to tectonosphere in following theses:(1) inhomogeneities are the potential Cn of different physical and chemical fields - stress, strain, temperature, fluid fields *etc.* These Cn may be named the structural-geological (tectonic) ones (TCn). (2) The function of geological medium is to lead itself to equilibrium with the aggressive outer conditions by decreasing (relaxing) the affecting outer forces. The processes of deformation, metamorphism, magmatism, erosion, sedimentation are the main mechanisms of such relaxation. All of these processes show the most activity in areas of TCn. (3) The larger TCn are the longer the periods of their life and more complex "set" of processes of different nature in their areas. Largest Cn such as regional or global deep faults live hundreds Ma., less intensive or smaller ones lives shorter. (4) The geological medium may create the new Cn if the initial set can't relax the affecting fields effectively (during the periods of structural reconstruction, bifurcation points in thermodynamic terms).(5) Tectonic evolution and modern geodynamics of concrete regions may be described as the process of relaxation and creation of Cn of different types and force.We use the physical modeling to mark out the most intensive and large TCn of Mediteranian Fold Belt and Russian Plate.

DEFORMATION PROCESSES IN THE CENTRAL ANDES - NEW DATA AND NEW PROBLEMS

Peter Giese, Freie Universität Berlin
Reporter: Collaborative Research Center 267

Geoscientific institutions in Berlin and Potsdam have launched an interdisciplinary research project "DEFORMATION PROCESSES IN THE ANDES", aiming to investigate the structure and the evolution of the lithosphere of the Central Andes between 20°S to 26°S. One of the main problems of the Central Andean evolution refers to the large thickening of the crust. The crustal thickening in the backarc can be associated to the young compressional processes in the Subandean thrust and fault belt. In contradiction tectonic balancing studies show, that the thick crust beneath the forearc must be explained by other processes. Magmatic underplating, tectonic erosion and basal accretion and/or undercrusting by a hydrated mantle wedge are possible processes to build up a thickened crust. New geophysical, geological and geochemical data are described which may help to understand the nature and evolution of the Andean lithosphere. Due to the various processes recently going on in the Central Andes different MOHO types must be distinguished.

SVEKALAPKO: A STUDY OF THE CRUSTAL EVOLUTION AND LITHOSPHERIC STRUCTURE OF THE BALTIC (FENNOSCANDIAN) SHIELD

S.-E. Hjelt (Dept of Geophysics, Univ of Oulu, POB 333, FIN-9571 Oulu, Finland)
J S Daly (University College Dublin, Univ Dublin, Ireland) and SVEKALAPKO PI's

The multidisciplinary EUROPROBE SVEKALAPKO project is designed to investigate the evolution and deep structure of the Precambrian Baltic (Fennoscandian) Shield along a northeast-southwest transect from the Barents Sea to Central Finland. The major aims of the SVEKALAPKO project are (i) to determine the geometry, thickness and age of the lithosphere and the disposition of major lithospheric structures in the Baltic (Fennoscandian) Shield and (ii) to define the crustal evolutionary history along the transect through three major crustal segments - two contrasting Palaeoproterozoic orogens, the Lapland-Kola and Svecofennian, and the intervening Karelian craton. The project has 10 subprojects ranging from geological, geochemical and geochronological studies of the Kola region to deep seismic and electromagnetic investigations to reveal the detailed deep structure of the lithosphere-asthenosphere system around the thickest Precambrian crust on Earth. A general overview of the SVEKALAPKO project is given together with first integrated tectonic, geothermal and reflection seismic results from the study area. The preliminary plans for deep seismic studies using passive tomography and active diving wave and reflection tomography as well as a unique EM 49 station array study are also described.

THERMOMECHANICAL LITHOSPHERIC STRUCTURE OF THE FENNOSCANDIAN SHIELD

P. Kaikkonen (Department of Geophysics, University of Oulu, Oulu, Finland)
K. Moisio (Department of Geophysics, University of Oulu, Oulu, Finland)
M. Heeremans (Research Schoool of Sedimentary Geology, Vrije Universiteit, Amsterdam, The Netherlands)

The present day thermomechanical structure of the Fennoscandian Shield was investigated by constructing strength profiles as a function of depth for five different DSS profiles. The DSS profiles BALTIC (including its southern continuation, the Sovetsk-Kohtla-Järve profile), SVEKA, the northern part of BABEL, POLAR and Pechenga-Kovdor-Kostomuksha, were used. These profiles are located in different tectonic units which represent different stages in Precambrian crustal and lithospheric growth. First, present-day geotherms were constructed for several points along the profiles. Successively, strength profiles were constructed using the obtained geotherms and rheological flow laws. Variations in heat production and strain rate were considered in the computations of the geotherms and the strength profiles. The integrated crustal and lithospheric strengths, the thicknesses of the mechanically strong crust and lithosphere and the effective elastic thickness were derived from the strength profiles. The obtained mechanical structure for different regions was analysed and compared to other geophysical data, e.g. a seismicity-depth distribution. The modelling results show lateral variations in the lithospheric strength reflecting the geometry of the lithosphere and following the same trend as the geochronological development of the Fennoscandian Shield.

3-D VERSUS 2-D FINITE DIFFERENCE SEISMIC SYNTHETICSWITH REAL SURFACE TOPOGRAPHY

S.O HESTHOLM, E.S. Husebye, and B.O. Ruud (Inst. Solid Earth Physics, UoBergen, Allegaten 41, N-5007, Bergen, Norway)

Three-dimensional (3-D) and 2-D finite-difference (F-D) modeling of scattering from free surface topography have been pursued and compared. A velocity-stress formulation of the full elastic wave equations with exact boundary conditions for a free surface topography has been numerically discretized by an 8th order F-D method on a staggered grid. We have simulated scattering from teleseismic P-waves using a plane, vertically incident P-wave and real topography from a 60x60 km area including the NORESS array in south-eastern Norway. Results are compared for a topography surface versus a plane surface and 3-D modeling versus 2-D modeling. Many field observations that are not easily explained by the simpler cases are shown to better match qualitative effects from 3-D modeling. These include strong amplifications at hills, complex wave pattern from scattering, and dirctionality dependence of scattered waves. Snapshots and seismograms show clear conversion from P-to-Rg waves in the area of rough topography near the mentioned array - all these results are consistent with numerous observations. By the parallellization of the software codes, possibilities have been opened for modeling with higher resolution and/or larger ares than ever before.

FACTS AND FICTIONS IN DERIVED REFRACTION PROFILING MODELS

E.S. Husebye, T.V. Maardalen, and B.O. Ruud (Inst. Solid Earth Physics, UoBergen, Allegaten 41, N-5007, Bergen, Norway)

We explore the adequacy of detailed, stratified modeling of the crust and based on long range seismic refraction and wide-angle profiling surveys. The real issues at hand are to what extent deterministic structure models are appropriate and likewise whether ray theory synthetics are a realistic and convenient tool in analysis of such data. Our approach to these problems were to compute 2D FD synthetics for published crustal models within the Baltic Shield; we used both the original models and their randomizations introduced through von Karmann functions of order 0.3 and 3 % RMS velocity fluctuations. The synthetics extended out to 450 km, imply that intercrustal reflections at critical angles and beyond should be most clearly observable in the distance range 60 - 100 km (crustal thickness 35 - 40 km). Beyond distances of ca 100 km the wavefields are dominated by the classical phases like Pg, Pn and PmP (Moho) phases and strong coda waves of long durations. In the perturbed model wavefield synthetics many of weak layer discontinuities are not observable seismically. In contrast the subjective analyst phase pickings are mainly in the 100 - 300 km distance range (strong coda waves) and this in combination with ray tracing synthetics being dissimilar to real records, appear to explain endproducts of overly detailed, deterministic crustal models rated partly fictive.

GEOTHERMAL STUDY OF PERMEABLE ZONES IN CRYSTAL BASEMENT

N.N. Khristoforova, A.V. Khristoforov (Kazan State University, Kremlevskaya Str., 18, Kazan, 420008, Russia)

We have used temperature measurements in Novo-Yelhovskaya 20009 well to reveal permeable zones in crystal basement. The well is situated on the Russian platform. Temperature measurements were made at depths of 1800 to 5365 m by section points in 0.2 m. Sensibility of a temperature sensor is 0.05 °C. We have discovered 48 large temperature anomalies and 34 zones, where temperature gradient changes sharply. Nine different types of temperature anomalies can be distinguished here. Their magnitude and quantity are increased with the depth increasing. There are series of anomalies attaining 100 m thickness at depths below 4000 m. We assume that revealed temperature anomalies are related to permeable zones in crystal basement. Potential collector properties of abnormal zones are estimated.

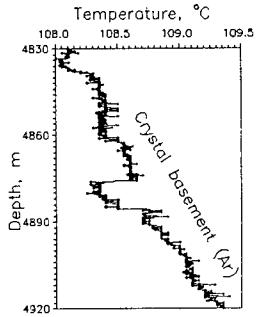


Figure. Temperature anomaly at depths from 4876 to 4885 m is the evidence of permeable (disturbance) zone in crystal basement of the 20009 well.

TEMPERATURE AND HEAT FLOW INVESTIGATIONS IN DEEP CRYSTAL BASEMENT

A.V. Khristoforov, N.N. Khristoforova (Kazan State University, Kremlevskaya Str., 18, Kazan, 420008, Russia)

We made experimental temperature measurements in deep crystal basement in 11 wells. The wells are situated at central-eastern part of the Russian platform. The measurements were made up to a depth of 5365 m by a section points in 1-0.2 m. The temperature at a depth 5365 m is 114.7 °C. Temperature gradient varies from 0.7 to 5.0 °C/100m. The mean temperature gradient (G) is about 2 °C/100m and remains almost constant with the depth increasing. A heat conductivity of crystal basement is about 3.1 $W m^{-1} K^{-1}$ Heat flows in deep crystal basement are from 55 to 65 $mW\ m^{-2}$. These values coincide with heat flows in lower layers of sedimentary strata. We have revealed temperature anomalies in certain wells. They may be considered as unconsolidated penetrable zones in crystal basement.

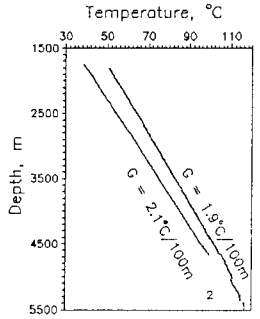


Figure. Temperature distribution in the ultradeep (1) Novo-Yelhovskaya 20009 and (2) Minnibaevskaya 20000 wells.

ADDITIONAL INFORMATION ON THE DEEP STRUCTURE OF TEISSEYRE-TORNQUIST ZONE (TTZ) BASED ON JOINT SEISMIC AND GRAVITY DATA MODELLING

Kozlenko V.G., Yegorova T.P., Starostenko V.I.

Institute of Geophysics, Nat. Acad. Sci., 32 Pr.Palladin, Kiev 252680, Ukraine

On the LT-7 profile, crossing the north-western part of the TTZ, the domains characterised by anomalous P-wave velocity/density relation was found in the axial part of the transition zone of 100-km width. By analysing this anomaly a conclusion about the manifestation of recent activation of geodynamic processes in the middle and lower crusts was made. This activation may be caused by anomalous (heated?) masses located in the layer with V_p=7.7 kms^{-1} which covers on the 50-55 km depth the uplift of the M2 boundary according to model of Guterh et al. (1994). Upper mantle heterogeneities over the TTZ are assumed to be propagated down to a depth of 200 km. Gravity modelling of the density equivalent of this heterogeneity was carried out.

THE N-GERMAN BASIN: DEKORP-CAMPAIGN *BASIN '96*

C. Krawczyk (GFZ Potsdam, Telegrafenberg, D-14473 Potsdam, Germany; ckrawe@gfz-potsdam.de)
E. Lück, M. Stiller, & *BASIN '96* Working Group (GFZ Potsdam)

Spanning from the Sorgenfrey-Tornquist-Zone to the Harz Mountains, the North German Basin forms an intracontinental basin of hotly debated geodynamic evolution. The suture zone between caledonian and variscan basement, the nature of the crust-mantle boundary and the structure of the upper mantel were investigated by reflection, wide-angle and refraction seismic measurements during ***BASIN '96*** (**B**asin **A**nalysis and **S**eismic **I**nvestigation in **N**orth Germany).
To decide about dynamic cooling, wrench or crustal extension models, DEKORP collected 800 km of marine seismic data in the Baltic Sea, combined with an onshore survey. 450 km of Vibroseis data (6 heavy vibrators, 10-50 Hz upsweep, 21 km spread, 60 m geophone spacing, 60- fold) and 90 explosive shots (90 kg/shot) were recorded on two orthogonal traverses, supplemented by 11 cross lines (4 km spread, 80 m geophone spacing) recording the dynamite shots of the main line as well as active vibroseis shots for possible cross dip interpretation.
The first reflection seismic data reveal a well stratified sedimentary column, a reflective lower crust in the northern part of the basin (11-12 sec TWT) and several mid-crustal structures which may give a key to the geodynamic interpretation of the North German Basin.

EXHUMATION OF SUBDUCTED CRUST IN THE SAXO-THURINGIAN BELT, E-GERMANY

C. Krawczyk (GFZ Potsdam, Telegrafenberg, D-14473 Potsdam, Germany; ckrawe@gfz-potsdam.de)
E. Stein (IGL Giessen), DEKORP & Orogenic Processes Research Groups

Previous seismic studies have revealed the importance of crustal stacking in the Variscan Belt suggesting that the Saxo-Thuringian belt of E-Germany has not only been overthrust by crystalline nappes, but partly exposed HP rocks of antiformal structure in a metamorphic core complex.
DEKORPs vibroseis-campaign in November 1995 was targeted at structural resolution (receiver spacing 30/35 m, upsweep 12-100 Hz) and understanding of post-orogenic reequilibration processes of previously thickened orogenic crust at the Granulite Massif.
The two reflection seismic profiles show a shallow high velocity- and high reflectivity-layer (Vp=6.0-6.5 km/sec) which correlates with serpentinites and ultramafites in the transition between the granulite and the schist belt.
We propose as geodynamic model for the Saxo-Thuringian, that the whole sedimentary column consists of allochtonous nappes on subducted and exhumed continental basement of unknown origin, coming originally from the Mid-German Cristallyne Rise or the Rhenohercynian to the North.

THE DEKORP-EXPERIMENT *BASIN '96*

E. Lück (GFZ Potsdam, Telegrafenberg, D-14473 Potsdam, Germany; erika@gfz-potsdam.de)
M. Stiller, C.M. Krawczyk (GFZ Potsdam)
U. Polom, U. Prochnow (DPC Clausthal)

The North German Basin extends from Bornholm in the N (Sorgenfrei-Tornquist-Zone) to the Harz mountains in the S, and from the North Sea to Poland. It shows a complex image with various geophysical anomalies, magmatic intrusions and several changes in the tectonic regime and fault systems.
The seismic investigations of the DEKORP-campaign ***BASIN '96*** (**B**asin **A**nalysis and **S**eismic **I**nvestigation of **N**orth Germany) aim to develop a geodynamic model of the formation of this intracontinental basin (dyn. cooling, wrench, crustal extension), to image the suture between caledonian and variscan basement, and to reveal the nature of the crust-mantle boundary and possible upper mantle structures.
From Sept. to Dec. 1996, DEKORP therefore recorded 455 km of vibroseis and dynamite data in the North German Basin (line 9601: 370 km, NE-SW trend; line 9602: 85 km, NW-SE trend), connected to 800 km of marine seismic data acquired in April 1996, supplemented by cross line-, wide angle- and refraction seismic recordings. Finally, these new profiles cover deep drill holes (7 km) and couple existing (industry) profiles in the western and eastern part of the basin.

SOURCE INVERSION OF TWO MODERATELY LARGE EARTHQUAKES IN THE TAURUS-ZAGROS THRUST BELT

Mahrdad MOSTAFAZADEH[1,2], Ömer ALPTEKİN[2] and Ali Osman ÖNCEL[2]
1.Meydane Ghasr Kuche Nader No18 Post Cod 16399. Tehran-IRAN.
2.Istanbul University, Department of Geophysical Engineering, 34850 Avcilar/Istanbul-TURKEY

The generalized linear inverse technique has been applied to the problem of determining earthquake source models of two moderately large earthquakes (29 April 1987, 01:45:26 GMT, M_S=5.9; 12 July 1986,07:54:30 GMT, M_S=5.7) in the Taurus-Zagros Thrust belt for a better understanding of recent tectonic activity along the thrust zone where many large and damaging earthquakes occurred in the instrumental and historical periods. These earthquakes occurred in the south of Zagros seismic zone, which is about 300 km wide, that coincides with the Zagros folded belt of southern Iran. This folded belt and the northeast-dipping Zagros fault or crush zone that borders it in the north extends about 1500 km from the Taurus mountains in the southeastern Turkey to a northerly trending transcurrent structure at the strait of Hormos. Propagation and instrument effects are deconvolved from the long period P wave records of WWSSN stations to obtain the teleseismic source time function using a damped least square inversion. The inversion has the additional constraint that the source time function is positive everywhere. Inversion resulted to a thrust faulting mechanism for each earthquakes. The estimated seismic moments are 1.95E+16NM and 2.28IE+16NM, and the fault parameters are (strike=99°, dip=60°, rake=34°, depth=29 km) and (strike=46°, dip=23°, rake =43°, depth=25 km) for the two earthquakes respectively.

TECTONICS, DEEP STRUCTURE AND THERMODYNAMIC HISTORY OF THE KOLA-BELOMORIAN INTRACRATONIC COLLISION BELT : PETROLOGICAL CONSTRAINTS FOR GEODYNAMIC AND GEOPHYSICAL SIMULATIONS

Mitrofanov F.P., Vinogradov A.N., Petrov V.P., Filatova V.T. *(Geological Institute of the Kola Science Centre, Apatity, Russia)*

On the base of modern petrological and geochemical studies in the Western part of the Kola Peninsula upgraded geological models were created. It was shown that the Paleoprotozoic Kola-Belomorian intracratonic collision zone including the Lapland Granulite Belt (LGB) and margins of the Belomorian and Kola domains was formed at 2.4 - 1.8 Ga as a feedback on stress in a set of terranes of the post-Archean craton localized between two riftogenic spreding zones (Imandra-Varzuga-Pechenga and Karashjok-Vetrenny Poyas). The hyperbaric metamorphic regime was realised along front zone of the Kola domain during overthrusting on the northern margin of the Belomorian domain . In the LGB a variation of P recorded by mineral geothermobarometers is ranged of 5 to 12 kbars and physical simulation gives evidence that local anomalies could reached up to 50 kbars. In the recambent terranes between LGB and IVP rift a basement was reworked under P-T regime of the sillimanite-andalusite series. After closing of rifts the stressed interrift belt was intruded by granite-porphyry stock surrounded by rim of explosive breccia that gives a clear evidence of a post-collisional decompression in the Kola domain margin. In contrary to that the underthrusted Belomorian domain show P-T regime of the kyanite series along all stages of reworking.

MELEKESS DEPRESSION: TECTONIC RECONSTRUCTION ON GEOPHYSICAL DATA

Nouria G. Nourgalieva (Faculty of Geology, Kazan University, Kazan, 420008, RUSSIA)

It have been created the tectonic reconstruction of the Melekess depression on different geophysical data: gravity, seismic, electrical surveys and logging results. This reconstruction have been discussed in the light of several positions in the geotectonics: theory of overthrust nappe and sedimentary cover fold structures, structural stability and relation of compensated high and non-compensated trough. Multivariate statistical analysis have been used for separation of slow tectonic movements before and after Late Permian. After Late Permian faulting effect was excluded out from considered part of basin sections. Local paleogeomorphological maps and relatively levels of Later Permian layers have been used for the prediction the paleorelief.

THERMO-MECHANICAL MODEL OF EVOLUTION OF LAYERED LITHOSPHERE IN CONTINENTAL COLLISIONAL ZONES

O.I. Parphenuk (United Institute of Physics of the Earth RAS, 10 B.Gruzinskaya, Moscow, 123 810, Russia)
J.-C. Mareschal (GEOTOP,UQAM,CP8888, succ A, Montreal, H3C3P8, Canada)

A thermo-mechanical model of continental collision including lower crustal flow is developed. The temperature, velocity and stress distribution are calculated based on 2-D model of collision simulated by shortening event which led to mountain building by overthrusting in the brittle upper crust and the formation of the thickened lower crust by ductile deformation. Finite-element 2-D modelling was used to examine the conditions under which ductile flow of the rheologically layered lower crust and upper mantle can produce the structure with crustal roots and surface uplift as a result of shortening, loading and erosion. The numerical calculations show that viscous flow at the depth of the lower crust and upthrusting of the brittle upper crust can be feasible mechanism, leading to the structural formation with crustal roots. The amount of crustal thickening and the tectonic stresses required to sustain shortening and overthrusting constrain the range of viscosity values to 10^{21} - 10^{22} Pa s in the lower crust for 10^{-14} s^{-1} strain rate. The deformation history of the region that was shortened during the compression has considerable effect on P-T-t paths mainly due to significant change of a position of a material point.

GEODYNAMICAL NUMERICAL MODELLING ALONG THE DSS PROFILE BALTIC IN THE FENNOSCANDIAN SHIELD

K. Moisio (Department Of Geophysics, University of Oulu, Oulu, Finland)
F. Beekman (Department of Earth Sciences, Vrije Universitiet, Amsterdam, The Netherlands)
P. Kaikkonen (Department Of Geophysics, University of Oulu, Oulu, Finland)

Numerical modelling was carried out for studying the present-day state of stress and deformation under different tectonic loading conditions along the DSS profile BALTIC in SE Finland. The finite element method (FEM) was used for solving the geodynamic problem. A two-dimensional model was constructed by using the results from both seismic and thermal studies along the profile. The large negative gravity anomaly of the Wiborg rapakivi area and the anomalously high Moho depths (> 60 km) in the Lake Ladoga-Bothnian Bay zone (LBBZ) are located in the profile. The 2-D model was 700 km long and 200 km deep and it was roughly divided into the inhomogeneous and horizontally layered crust and the homogeneous lithospheric upper mantle. Both linear elastic and nonlinear elasto-plastic rheologies were applied. Elasto-plasticity was achieved by calculating a plastic yield strength as a function of depth in each point where lithology or geotherm is varying. Different tectonic load cases include displacement and force boundary conditions with and without gravitational effect. Gravitational stresses are achieved by using relative densities. Distribution of stresses under different tectonic conditions was studied. Deviatoric state of stress and other indicators for brittle and ductile rock failure and deformation were investigated. In the elasto-plastic cases possible areas of yielding were estimated.

TECTONIC DEFORMATION OF SOUTHERN PART OF THE YANGTZE CRATON INFERRED FROM PALEOMAGNETIC STUDY

Y. OTOFUJI and M. YOKOYAMA (Department of Earth and Planetary Sciences, Kobe University, Kobe 657, Japan), M. TAMAI (Department of Geology and Mineralogy, Kyoto University, Kyoto 606, Japan), and Y. Y. LIU (China University of Geosciences, Wuhan 430074, China)

Upper Cretaceous red sandstones have been sampled at 21 sites from the Jiangdihe 2 and Jiangdihe 3 Formations in Yuanmou (25.8 °N, 101.7°E), northern part of Yunnan, China. Characteristic directions with unblocking temperature of 680 °C are isolated from all of the sites, and provide a positive fold test which is significant at 99 percent probability level. Remanent magnetization of the pre-folding origin represents a characteristic direction of the Jiangdihe formation (D=26.9°, I=35.6°, and α95 = 3.6°). Incorporating this results into the previous data, the Cretaceous paleomagnetic direction of the southern part of the Yangtze craton is characterized as easterly paleomagnetic direction (D=27°~45°). This is in contrast with the paleomagnetic directions for interior of the Yangtze craton (Ya'an, Xichan, Huili) where northerly direction is predominant (D=2°~8°). The easterly direction on the south of the Yangtze craton is ascribed to tectonic rotation in clockwise sense with respect to interior of the Yangtze craton. A declination plot in the Yangtze craton as a function of distance from southern boundary of the Yangtze craton (Red River fault or Jinsha suture) indicates that large clockwise rotation gradually decreases as the distance increases. Stress, that causes deformation of the Qiangtang and Shan-Thai-Malay blocks, seems to invade the craton up to 220 km from the block boundary. The Yangtze craton behaved as a non-rigid material against the stress due to collision of continents.

CRUSTAL TYPES OF THE EUROPEAN CONTINENT AND ITS MARGINS, AND EVOLUTION OF THE CRUST.

N.I.Pavlenkova. Institute of Physics of the Earth, B. Grusinskaja 10, 123810, Moscow, Russia

In Europe and the North Atlantic all basic crustal types are observed. The thick (40-45 km) continental crust with so-called "granite" layer (seismic velocities V ~6.0-6.4 km/s) is typical for the East Europe, the thin (25-35 km) continental crust - for the West Europe, the oceanic crust (thickness of 5-7 km, V ~6.5 km/s) - for deep oceanic basin. The continent margins are build from subcontinental (15-25 km, thin layer with V ~6.0-6.4 km/s) to suboceanic types (10-25 km without the "granite" layer). Deep continental basins with sediment thickness more than 10 km is also characterized by the suboceanic crust. Close correlation is observed between the crustal types and age of the tectonic units, tectonic activity, position relatively to the continental margins, structure of the uppermost mantle and the mantle transition zone, heat flow, and the geoid anomalies. The observed correlation suggest that this area is an area of destruction of the continental crust and its transformation into suboceanic type. This process may be due to the tectono-magmatic activation regime generated by the mantle heat and matter. The high heat flow, lower mantle velocities and the geoid positive anomaly mean that the heat and matter were going from the transition zone between the upper and lower mantle, they penetrated into the crust through rifts, deep basins, faults and modified the crustal rocks. The final stage of this process are the suboceanic or oceanic crusts. Crustal structure of the deep sedimentary basins suggest their formation as a result of such process without large stretching. Deep drilling data show that the North Atlantic is covered with the shallow water sediments, so the ocean also might be created by the modification of the former continental crust.

DEEP STRUCTURE OF THE SWISS ALPS: TECTONIC EVOLUTION AND GEODYNAMIC MODELING

O.A. Pfiffner (Geol. Institut, Baltzerstr. 1, CH-3012 Bern, Switzerland)
S. Ellis and C. Beaumont (Department of Oceanography, Dalhousie University, Halifax, N.S., B3H 4J1 Canada)

Seismic data on the deep structure of the Swiss Alps suggest that the classic Alpine nappe pile is a bivergent stack of upper crustal imbricates, overlying an asymmetric lithosphere structure. This structure evolved in the course of Cenozoic, N-S oriented convergence. After subduction of oceanic crust, a continental fragment entered the subduction zone. Off-scraped oceanic and continental material was accreted to the hanging wall in this phase (nappe formation). Subsequently backthrusting developed, which initiated widespread exhumation of high grade rocks. In a final collisional stage more material was accreted to the upper plate and pro- and retro-shearing, combined with erosion led to the exhumation of high grade rocks. Dynamic modeling emphasizes the importance of mechanical contrasts. A mechanical layering with a very weak uppermost layer (representing sediments), a weak upper and a strong lower crust results in two separate detachments. The uppermost detached layer is strongly shortened ; critical taper geometry is maintained by vertical stretching. Weak upper crust of normal crustal thickness gets shortened and sheared off the lower crust and accreted to the upper plate, whereas extended crust from continental margins is more likely to remain attached and subducted to greater depths. Changes in subduction angle significantly influence the advection of material to the hanging wall and the development of backthrusting.

TECTONICS AND MORPHOLOGY OF THE CRYSTALLINE BASEMENT IN ROMANIA

G.Polonic (Institute of Geodynamics of the Romanian Academy, 19-21, J.L.Calderon Str., 70201, Bucharest, Romania)

The paper presents the structural and morphological model of the crystalline basement surface in Romania, achieved by analysing a vast seismometric material, completed with deep seismic sounding, reflection profiling and borehole data. The map was drawn at a marker bed identified with a sedimentar cover/crystalline basement limit for the foreland and with the sedimentary/crystalline limit of the Dacidic units, under the Transylvanian nappes, for the Intra-Carpathian alpine regenerated area.

Starting from the structural model of the crystalline basement, correlated with the known models at the level of the Conrad and Mohorovičić discontinuities, a more accurate delimitation, by crustal faults, of the three major compartments of the Romanian territory was settled: the European Plate, the Moesian and Intra-Carpathian microplates, as well as the geological units which compose them, for a better understanding of their interaction.

MANTLE AVALANCHES AND THE DYNAMIC TOPOGRAPHY OF CONTINENTS

Russell N. Pysklywec and J. X. Mitrovica (Department of Physics, University of Toronto, 60 St. George St., Toronto, Canada, M5S 1A7)

A number of studies have shown that viscous forces associated with mantle flow are capable of supporting considerable vertical deflections (i.e., dynamic topography) of the overriding lithosphere. Recently, it has been suggested that mantle convection consists of primarily layered flow (above and below 670 km depth) punctuated by episodes of dramatic downwelling (or "avalanche") events. We consider, in detail, the dynamic topography of continents associated with these events. Our simulations integrate 2-D multi-phase mantle models with 'beam' models of the continental lithosphere. We find that avalanche events support regional vertical deflections of up to $\sim$ 2.5 km depth. The horizontal length scale of the dynamic topography is $\sim$ 2000 km and non-negligible deflections can persist on the order of 100-200 Ma. We also find that convergence rates in regions surrounding the continents are variable but reach rates of $\sim$3 cm/a. This convergence leads to tilting at the continental margin. Finally, we argue that an avalanche event may have been active beneath Laurussia from the Late Silurian to Late Carboniferous. Tectonic reconstructions indicate that Laurussia was ringed by convergence over this time period (leading to Pangean aggregation). Furthermore, stratigraphic data indicate the development of the large scale, deep intracontinental basin system in the western interior of North America during this period (Ziegler, 1989) as well as long-wavelength sedimentation on the north-east margin of the continent (the Russian Platform).

REMOVING VARYING DIRECTIONAL TRENDS IN AEROMAGNETIC DATA: A TECHNIQUE TO FACILITATE TECTONIC INTERPRETATION

Mark Pilkington and Walter R. Roest (Geological Survey of Canada, 1 Observatory Crescent, Ottawa, Ontario, K1A 0Y3 CANADA)

Both qualitative and quantitative interpretation of regional aeromagnetic data can be hindered by the presence of linear magnetic anomalies due to mafic dykes. These linear trends often truncate and interrupt magnetic anomalies due to magnetization contrasts, making the tracing of such features ambiguous. Similarly, any subtle magnetic texture within lithological units may be obscured by the presence of dyke anomalies. In addition, automated methods for source parameter estimation may respond preferentially to the dyke sources at the expense of other, more useful source information. Since dyke swarms are often nonparallel (fifty percent of swarms in North America exhibit a fanning pattern) simple frequency-domain strike-sensitive filtering based on a single directional trend is not a viable method for removing their signatures. We use a coordinate transformation to reproject the varying dyke directions onto a single azimuth. Anomalies along this single trend can then be removed by standard directional filtering. Once the grid is decorrugated the opposite transformation can be applied to obtain a grid at the original grid location and orientation. We use the coordinate transformation approach to suppress the anomalous effects of the Mackenzie dyke swarm that contributes significantly to the magnetic field over the Slave structural province, Northwest Territories, Canada, and show that the remaining field is more suitable for quantitative analysis, tectonic interpretation and correlation with the regional geology.

RECENT TECTONICS AND SEISMICITY OF THE URALS.

B.P.Ryzhiy, V.S.Druzhinin, A.N.Guliaev. Institute of Geophysics of theUrals branch of Russian Academy of Sciences. Ekaterinburg,Russia.

The Urals is a region of recent tectonics , where velocity of vertical movements is from — 2,5 to + 6,5 mm / year. During the last 300 years about 70 seismic events with the magnitude of 3,0- - 5,5 were registered here. Sources of earthqakes occur at the depth of some km to 40 km and are localized in some seismogenious zones, restricting the neotectonic Urals orogen. Everage distances between epicenters with intensity of 6-7 balls is about 200km, 5-6 balls is about 80 km, 4-5 balls -40 km. There is a 60-year period in increasing of seismic activity. Events with the intensity of 7 balls take place each 100+ 15 years. Take place a relationship between a deep tectonic and seismicity.

THE URALS LOCATION IN THE STRUCTURES OF THE EURO-ASIAN CONTINENT

B.P.Ryzhyi, O.Ya.Belyaeva (Institute of Geophysica UB RAS, 620016 Ekaterinburg, Amundsen str. 100, Russia) B.B.Ryzhiy (Urals Government Mine Academy)

The geological-geophysical information along the transects of the Baltic Shield - Urals super-deep borehole (USDB), Ukrain Sield - USDB and USDB - Okhotskoye sea was analyzed here. The crustal sections (Yegorkin A.V., Kostuchenko S.L., Kashubin S.N. et al.) were compared with the thickness of the faunal characterized sedimentations by 16 temporary periods (Spijharsky T.N. et al.) It was stated that: 1. Along the whole extent of the transects there was noted only one event, when the crustal upwarping of the huge block corresponded to the prolonged sinking of the adjacent block. That occured right from the Middle Devon on the Western border of the Urals system. 2. The Middle Upper Devon is the period when begins and sharply strengthens the sedimentation in the basins of the Verhoyansko-Tchukovskoye folded region, Viliuskoye syneclise, Ob-Tarovskoyi sineclise, PreUrals edge sag and Dneprovsko- Donetsky avlakogene. This work was fulfilled thanks to the Russian Fund of Fundamental Researches grant No. 96-05-65660.

DISTRIBUTION OF THE DEEP-SEATED MASSES IN THE URALS REGION

B.P.Ryzhyi, O.V.Bellavin, V.S.Druzjinin , N.I.Nachapkin (Institute of Geophysics UB RAS, 620016 Ekaterinburg, Amundsen 100, Russia)

The Urals geosyniclinal belt according to the geological- geophysical data is the result of continuous endogenic process within the limits of indivisible integral structure, that is particularly testified by the results of Bouguer anomaly analysis. The isostatic and "in free air" anomalies to the north and to the south from 55° N latitude in the Urals and adjacent regions are different. In the north the intensive positive anomalies are observed, in the South they are close to zero or are negative. The distribution of anomaly masses, estimated by deep seismic cross section indicates, that the sources of those anomalies are absent; they are situated below in the upper mantle. That coincides well with the geoid surface of the Urals region. The difference in northern and southern sections of magnetic fields proves that the regional inhomogenousness exist in the crust. This is confirmed also by cosmogeological data. The complex analysis of all the materials permits to conclude, that the processes occuring in the lithosphere in the Urals formation period in the North and in the South were significantly different; they also affected the peculiarities of the crustal structure and composition.

ABOUT PECULIARITIES OF THE URALS MOBILE BELT STRUCTURE

B.P.Ryzhyi, V.S.Druzhinin (Institute of Geophysics, UB RAS, 620016 Ekaterinburg, Amundsen str. 100, Russia)

Analysing the Urals structure peculiarities there were taken into account the Moho (M) division surface and the early Archean cristal basement (K_{01}) by deep seismic soundings (DSS) data. The distinguish of the interior structure of the Urals mobile belt was determined in the Polar Urals, North-Urals, Middle-Urals and the South-Urals zones. Within the limit of the European Shield and the Western Syberian Plate sharp distinctions of the Moho (M) and K_{01} surface depths from other sections were established for the Middle Urals megablock. The similar peculiarity of the structure was revealed by other geological-geophysical methods in the earth crust and the upper mantle structure.

ARCHITECTURE OF THE CONTINENTAL CRUST OF CENTRAL-EAST GREENLAND: AN INTEGRATED GEOPHYSICAL APPROACH

V. Schlindwein and W. Jokat (AWI, Columbusstr., D-27568 Bremerhaven, Germany)

Central-East Greenland's continental lithosphere underwent a complex evolution since Archaean times. Its present structure formed during Caledonian orogeny, subsequent extension, extensive Tertiary magmatism and the opening of the North Atlantic.
Since 1988, the Alfred Wegener Institute for Polar and Marine Research (AWI) has examined the continental crust of North-East Greenland using different geophysical techniques. Refraction seismic profiles provide information on the seismic velocity structure of the crust along cross-sections following the major fjord systems. Reconnaissance aeromagnetic (AWI) and gravity (National Survey & Cadastre, Denmark) surveys give a regional overview over the coastal range of entire North-East Greenland.
Models of the continental crust in the Kong Oscar Fjord - Kejser Franz Joseph Fjord area are presented. The different data sets are combined for modelling and geological interpretation. The seismic data indicate an extended crust underneath the Mesozoic sedimentary basins along the coast with a high velocity layer (7.1 km/s) in the lower crust. The area coincides with a pronounced magnetic anomaly suggesting a possible Tertiary magmatic underplating. Westward the crust thickens beneath the Caledonian orogen to more than 40 km. Gravity data support the Moho topography.

Control of Fault Structure on the Seismo-Mechanics of major fault zones: The Dead Sea Transform

G. Shamir (Seismology Division, Geophysical Institute of Israel, P.O.B. 2286, Holon 58122, Israel, e-mail: gadi@iprg.energy.gov.il)

The Dead Sea Transform (DST) has been the locus of pronounced seismic activity throughout historical times and has been characterized, since 1900, by non-uniform epicenter distribution. Earthquakes are mostly localized at major left-stepping discontinuities, where large pull-apart basins are formed, namely the Gulf of Elat/Aqaba and the Dead Sea, Kineret and Hula basins. Inter-basin sections of the DST are nearly devoid of seismic activity during this period. Two segments are discussed here: (i) In the Gulf of Elat/Aqaba, the seismically most active segment of DST, four left-stepping fault segments delineate three elongated pull-apart basins. Each step zones was the locus of distinct earthquake sequences, during the last 15 years. This defines a seismic segmentation in which activity of each segment promotes the next earthquake sequence on a neighboring fault. The Mw=7.1 Nuweiba earthquake of 22.11.95 ruptured an entire segment and caused intense aftershock activity in the two step zones (basins) at its ends (ii) The Hula basin, formed at a large left-stepping fault discontinuity, is the northern section of the Dead Sea rift. Relocation of seismic events occurring since the early 1980's reveals that most recent activity occurs within the basin, along transverse normal faults connecting the major DST faults. This implies that the basin is under strike-parallel extension and that the associated strain may load the major DST faults and promote future left-lateral earthquakes.

NUMERICAL MODELLING OF PRESENT-DAY GEODYNAMIC PROCESSES IN THE LITHOSPHERE BASED ON INTEGRATED GEOPHYSICAL AND NEOTECTONIC STUDIES.

E.I. Smolyaninova and V.O. Mikhailov (Institute of Planetary Geophysics, Russian Academy of Sciences, B.Gruzinskaya 10, 103810 Moscow, Russia)
R.A. Stephenson (Netherlands Research School of Sedimentary Geology, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, Netherlands)

We present the results of 2D numerical modelling of the present day tectonic movements and stress field of regions with contrasting geodynamic settings: the Caucasus, the Baltic Shield, and the continental margins of the Black and Beaufort seas. The deformation and stress modelling requires a knowledge of lithospheric structure (the distribution of density and mechanical properties) and a set of boundary conditions that can be interpreted in terms of regional tectonic processes. The structural information is derived from seismic and gravity data and the boundary conditions are chosen so that the calculated movements on the surface of the models matches observed neotectonic data. The calculated stresses are in turn tested against observed seismicity patterns. The models are therefore consistent with seismicity, seismic, gravity and neotectonic data. The modelling results suggest that present day deformation and stresses in some regions (the Caucasus, platform and shield areas) are mainly due to intraplate forces whereas in others, in particular at continental margins characterised by simultaneous onshore uplift and offshore subsidence, mantle processes may play an important role in determining the state of stress.

THE DEEP STRUCTURE OF THE NORTH GERMAN BASIN - FIRST RESULTS OF THE DEKORP CAMPAIGN *BASIN'96*

M. Stiller (GFZ Potsdam, Telegrafenberg, D-14473 Potsdam, Germany; manfred@gfz-potsdam.de)
E. Lück, C.M. Krawczyk, (GFZ Potsdam)

The experimental design of the DEKORP-campaign ***BASIN '96*** (**B**asin **A**nalysis and **S**eismic **I**nvestigation in **N**orth Germany) aimed to image deep crustal levels in the North German Basin below the base of the Zechstein, the 'marker horizon' in this area. Besides a 60fold vibroseismics, energy was also generated by dynamite shots, and the signals recorded in both steep- and wide-angle distance. 95 dynamite shots (90 kg/shot; 21 km spread, 60 m geophone spacing, off-end shooting, record length 64 s) on two orthogonal profiles result in 2fold seismic CDP sections (line 9601, 370 km; line 9602, 85 km). Partially correlatable steep-angle Moho reflections and numerous mid-crustal events provide a promising starting point for geodynamic interpretations and conclusions. Moreover, all explosive shots were recorded by 10 additional stations (8 channels each, 200 m geophone spacing, 90 s recording length) covering 18 km along the profile in wide-angle distances, either as a fixed spread resulting in 4 full offset sections 0-100 km or moving behind the shots within the critical COF range 60-90 km. Up to a distance of 100 km, clear and strong events of the Moho are observed, giving a base for velocity determinations.

INTEGRATED GEOPHYSICAL STUDIES OF SIRT BASIN, LIBYA

A.S. Suleiman (El Fateh University & Petrolume Recearch Center, Libya)
D I Doser and G R Keller (University of Texas at El Paso, 79968)

Sirt Baisn, a late Jurassic-Miocene sedimentary depression in northern and central Libya, is associated with a cretaceous age rift zone that extends through the area Results, as they relate to crustal structure, is presented through an integrated analysis of subsurface data, gravity readings, heat flow data, and seismicity data A data base of over 5000 gravity readings were used to construct a variety of filtered maps and delineate a prominent northwest-trending set of structures which clearly define the rift system. Using deep driling as constrints on both density and geometry, a computer models of crustal structure were constructed These models confirms the block-faulted nature of the basement beneath the basin as well as a crustal thinning beneath the rifted region The crustal thining is estemated to be in the order of 5 km with respect to adjacent stable platforms Heat flow is slightly elevated, but fairly uniform throught the basin Geologic evidence suggest that rifting continued into the Eocene and the region remains seismically active. The Western part of the basin, known as Hun Graben, was the site of several major earthquakes Inversion studies for stress direction in this part suggest a near-horizontal maximum compressive stress oriented N 97^0 E and a minimum compressive stress with a strike and plunge of 195^0 and 25^0 respectively

INTEGRATED GEOPHYSICAL INTERPRETATION OF THE TORNQUIST FAN AREA

H. Thybo, A. Lassen, T. Abramovitz, S. Zhou, and A. Berthelsen
(Geological Institute, University of Copenhagen,
Øster Voldgade 10, DK-1350 Copenhagen K, Denmark)

The Tornquist Fan is a northwestward widening splay of Carboniferous-Permian fault zones in the Danish area, emanating from the Tornquist-Teisseyre Zone of northern Poland. Integrated interpretation of geophysical data forms the basis for a tectonic model of this sediment-covered part of the Baltica plate which involve the Sveconorwegian orogeny; Caledonian collision; Late Palaeozoic wrench faulting; Mesozoic basin formation and extension; and, latest, the Late Cretaceous to Early Tertiary inversion. The crust-mantle boundary shows an undulating topography which correlates with the main tectonic features as well as with other characteristics of the crust. Zones of high average velocity through the consolidated crust coincide with Bouguer gravity and magnetic anomalies in the deep basins and in the border zone of the shield. They are interpreted as Late Palaeozoic, magmatic features. Subsequent cooling and loading may have had strong implications for the formation of the regional Mesozoic basins. The trend of the Sorgenfrei-Tornquist Zone, as defined by compressional inversion structures, is parallel to the trend of the Tornquist Fan in its SE part but not in its NW part in the deep sedimentary basins.

Deep seismic investigation of the West and South Bohemian Massif

The deep seismic profile 9HR is 225 km long and from a geological point of view passes from the Saxothuringicum (Klingenthal area in Erzgebirge) through the Tepla-Barrandian Zone (Bohemicum) to the Moldanubicum (East of the south Bohemian granulite massifs). Seismic fabric observed is clearly different in the Saxothuringicum and Bohemicum on one side and in the South Bohemian Moldanubicum on the other side. Whereas Paleozoic and Cadomian seismic zones and sutures are relatively simple and monotonous and all dip to the Southeast, Moldanubian seismic crustal image is more complex. The most remarkable results of the 9HR line are: 1) Different upper crustal structure (3 - 4 s TWT) and middle/lower crustal seismic fabric beneath the Saxothuringicum and the Marianske Lazne metaophiolitic complex imposing the interpretation of tectonic detachment at the depth of 10 - 12 km. 2) Three whole crustal seismic SE dipping sutures. Whereas the origin of the Northern one existing beneath the Erzgebirge and the Karlovy Vary Pluton belongs hypothetically to the roots of East Avalonia, the central one is directly connected with the surface occurrence of metaophiolites and it is interpreted as an old Variscan suture and the Southern one is undoubtedly Cadomian as reflections of it reach the surface. 3) Southeast dipping reflections are observed about 40 km SE of the Klatovy (Bohemian- Moldanubian) boundary fault in the lower crust. These might be interpreted as Bohemian and it seems that the Moldanubicum itself is composed of several different Armorican fragments. 4) We interpret steep reflections dipping SE West of the South Bohemian granulites as late thrust faults on which the 340 Ma old granulites finally reached the surface. The line brings many excellent detail results as the transparent seismic fabric of Variscan plutons, reverse NW dipping seismic fabric of the Erzgebirge, Moho uplift in the young basaltic volcanism area, large megafold structure of the Bohemicum and synform and antiform seismic fabrics in the Moldanubicum.

STRUCTURE AND EARLY JURASSIC LITHOSPHERE DYNAMICS OF THE CAUCASUS AREA

V.V.Yutsis, A.N.Stafeev (Department of Dynamic Geology, Moscow State University, Moscow, Russia)

This paper is based on the results of the multichannel seismic reflection studies combined with other geophysical data including drilling. Seismogeological analysis shows evidence of the deep (from 0.5 to 1.5 km) and narrow (about 30 km) depressions, extended through the continental margin of Early Jurassic Tethys with E-NE trend. The detail paleogeographic and paleogeodynamic maps of the Caucasus and Peri-Caucasian Foredeep were constructed taking in account these structures. The most significant feature is that these graben-like depressions were oriented under the sharp angle to the axe of the Great Caucaus Foredeep. There are two different explanations of this tension fracture zone origination: (1) as a pericontinental foredeep and (2) as a result of the oblique subduction and back-arc basin formation.

AN INTEGRATED GEOPHYSICAL STUDY OF THE BASEMENT GEOLOGY OF THE SOUTHEAST NORTH SEA

S. Zhou and H. Thybo (Geologisk Institut, Københavns Universitet, Denmark)

In this study, we show geophysical evidence for the existence of substantial amounts of Palaeozoic sediments in the area of East North Sea High. The interpretation is based on a calculated residual gravity anomaly map of the area, which outlines the potential area of Palaeozoic sediments as indicated by relatively low residual gravity anomalies. Magnetic basement depths of a few selected areas are estimated using available aeromagnetic data. Re-interpretation of selected seismic sections confirms the results derived from the potential field investigations. The implications of this study are: (1) integrated geophysical investigation has enabled us to better understand the basement geology of the area; (2) the Palaeozoic structures revealed by seismic interpretation and potential field studies strongly suggest that extension tectonics is responsible for the development of complex basement structures underlying the well-documented sedimentary succession from Later Permian to Quaternary; and (3) the formation of the East North Sea High is likely to be caused by a deep crustal process such as mafic underplating in the Late Permian.

SOLID EARTH GEOPHYSICS (SE)

SE1 Dynamics of the upper mantle

Convener: Zeyen, H.
Co-Convener: Sabadini, R.

ROLE PLAYING BY THE OLIVINE-SPINEL PHASE CHANGE IN REGULATING THE DOWNWELLING PENETRATION IN THE LOWER MANTLE.

D. Brunet (1), D.A. Yuen (2), and P. Machetel(1)
(1) UMR5566 / GRGS / CNRS / CNES, 18 av E.Belin , 31401 Toulouse cedex 4, France)
(2) Dept. of Geology and Geophysics at Minnesota Supercomputer Institute, Univ. of Minnesota, Minneapolis; MN 55415-1227, USA

Recently, we have shown that the olivine-spinel phase change associated with a temperature dependent viscosity is able to decrease drastically the viscosity of the downwellings. This decoupling leads to the separation in two distinct parts of the current. A consequence of this phenomena could be the "ablative subduction" of slabs. We use the temperature at the Core Mantle Boundary (Tcmb) as a control parameter on the convective regime. Increasing the Core Mantle Boundary temperature makes the downwellings to be cut down more violently. In this configuration, only small "blobs" of cold material could cross the 670 km discontinuity. For intermediate values of Tcmb, some of them are not sliced and could sink deeper in the lower mantle. In the low Tcmb regime, all the cold material which cross the 400 km depth phase change are softened but rise integrally in the lower mantle.

PLATE STRENGTH IN OLD OROGENIC BELTS AND CRATONS.

E. Burov (*DR/GIG, BRGM, Orléans, France: burov@u127.brgm.fr*),
C. Jaupart (*Institut de Physique du Globe de Paris, Paris, France*)
J.-C. Mareschal (*University of Quebec, Montreal, Canada*)

Indirect spectral gravity methods commonly used to estimate the integrated lithospheric strength (EET) exploit the idea of strong correlation between the surface topography (*h*) and deflections (*w*) of strong upper mantle (*Moho boundary*): large *w*-to-*h* wavelength and *h*-to-*w* amplitude ratios are interpreted in terms of high EET (90-120 km). Domains of reported high EET (e.g., cratons) are associated with flattened relief and small gravity anomalies. The signal-to-noise ratio can be simply too poor to provide reliable estimates of EET. In such areas, much more coherent results can be provided by *direct* methods taking into account variations in the rheological structure, lithology and mechanical discontinuities (e.g., deep faults). We calculated the EET directly, from vertically and laterally variable brittle-elasto-ductile rheology profiles. Our technique is based on depth integration of stresses in actually inelastic lithosphere and finding equivalent elastic parameters. We studied the 2000 Ma old Kapuskasing uplift (Canadian shield), for which we show that crustal inhomogenities such as large scale faults and long-scale variations of rheological properties can be responsible both for strong (~40%) localised and large scale reductions of EET that cannot be picked up by the traditional methods. We suggest that analogous mechanisms could lead to strength reduction in most cratonic areas and old orogenic belts.

MANTLE CONVECTION AND THE "AVALANCHE EFFECT"

Sam Butler and W.R. Peltier (Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7)

A number of recent analyses of the mantle convection process have suggested that the endothermic phase transition that defines the base of the transition zone is capable of strongly inhibiting the vertical motion of material through this horizon (see W.R. Peltier, Phil. Trans. Roy. Soc. Lond. A, 354, 1425-1447, 1996 for a recent review). In the presence of this influence and in the absence of additional complexity, the circulation becomes strongly intermittent in style with relatively long periods of layered flow interrupted by relatively brief episodes of strong mass exchange between the material "reservoirs" that are separated by the phase boundary. During these episodes the radial mixing is controlled by intense "avalanches" of cold material from the transition zone into the lower mantle and, in this "whole mantle" state, flow kinetic energy rises dramatically (L.P. Solheim and W.R. Peltier, JGR, 99, 15861-15875, 1994). We have completed a new sequence of detailed simulations of the avalanche effect that incorporate a range of additional influences that have yet to be studied in detail, including that due to the increase of radial viscosity with depth. The latter influence is analysed using the specific radial profile of mantle viscosity that has been inferred on the basis of recently published formal inversions of the data of glacial isostatic adjustment (W.R. Peltier, Science, 273, 1359-1364, 1996). This viscosity structure has already been shown to fully satisfy the requirements of aspherical geoid anomalies. We focus upon the manner in which this variation modifies the "avalanche effect".

Structure of the continental and oceanic upper mantle - Comparative analysis

V. Geyko, T. Tsvetkova. Institute of Geophysics of National Academy of Sciences of Ukraine, av. Palladin 32, 252680 Kiev-142, Ukraine

We new large scale 3-D *P*-velocity models of the mantle beneath Europe (EUR-*P*G) and central Asia (CAS-*P*G) and generalised 1-D *P*-velocity models of the mantle beneath north Atlantic and south-west Pacific has been determined. The initial data have been first-arrival times of *P*-waves from major seismic events for 1966-1990. New method of seismic tomography proposed by V. Geyko has been used for inversion of the data. The following solid properties of the continental mantle have been explained. (1) The mantle is subdivided into the two shells by the global boundary situated at 550-680 km depth. The upper shell (tectonosphere) is notably inhomogeneous laterally, while the lower one is almost radially symmetric deeper 750-800 km. (2) Age and type of the tectonic structures are reflected in the tectonosphere. (3) The intermediate boundary of tectonosphere situated at 390-450 km depth and the astenosphere is not global. The former is peculiar to the ancient and formed structures and later to those actively living now. We have been found that the north Atlantic and south-west Pacific mantle has the such general features. (1) Absence of the 410 km discontinuity. (2) Presence in its upper part of a 200 km thick layer with a very week velocity increase with depth (such a manifestation is probably characteristic of the astenosphere).(3) The upper part of the mantle in the south-west Pacific notably differs by higher velocity compared to ones in the north Atlantic.

INFLUENCE OF AN INITIATING SUBDUCTION AT MID-OCEAN RIDGE ON UPPER MANTLE DYNAMICS - MAGMATIC IMPLICATIONS

D. Insergueix (Laboratoire de Physique de la Terre et des Planètes, Université d'Orsay, 91405 Orsay, France). L. Dupeyrat (Laboratoire de Géologie Dynamique de la Terre et des Planètes, Université d'Orsay), and J. Bébien (Laboratoire de Pétrographie-Volcanologie, Université d'Orsay)

Field studies of ophiolites and fore-arc domains suggest the existence of a large spreading process, leading to the creation of a new lithosphere. Such a spread is characterized by a very particular boninitic magmatism, involving partial melting of a refractory wet mantle at low depth. Those conditions would be relevant to an initiating subduction in the vicinity of a mid-ocean ridge. This original geodynamical configuration has been numerically investigated in a 2D convective domain modelling the upper mantle where surface and subducting plates displacements are prescribed by time-dependent kinematic boundary conditions.

Preliminary experiments indicate that the initiation of an intermediate-dipping subduction at ridge axis does not stop immediately the ascending asthenospheric flow but leads to a deviation of this flow under the overriding plate. Depending on the initial ridge spreading rate, kinematic reversal rate and subduction rate, the model predicts : i) a possible spread in the overriding plate, ii) a progressive extinction of the MORB magmatism, and iii) the short-time initiation then extinction of boninitic magmatism, partly contemporary with arc volcanism.

NUMERICAL MODELS OF ECLOGITIZATION-INDUCED MANTLE FLOW: APPLICATION TO BASIN SUBSIDENCE

A. T. Ismail-Zadeh and B. M. Naimark (Intl Inst Earthquake Prediction Theory & Math Geophysics, RAS, Warshavskoye sh. 79-2, Moscow 113556, Russia)
W. R. Jacoby (Institut für Geowissenshaften, Johannes Gutenberg-Universität Mainz, Saarstraße 21, Mainz 55122, Germany)

In many regions of the world, the uppermost mantle beneath intracontinental basins contains bright, regionally extensive, seismic reflectors. The gravity anomalies over the regions are usually high. These mantle reflectors are frequently found by deep seismic sounding and reflection studies, but their significance and geological origin remain obscure. We suggest a mechanism of basin formation which can help to explain these observations. The mechanism is based on the processes of extension, magmatism, and eclogitization in the uppermost mantle. Heavy eclogitic bodies evolve as the result of these processes and sink in the asthenosphere. This induces a viscous flow changing the surface topography and forming a sedimentary basin. We constructed two- and three-dimensional numerical models describing eclogitization-induced mantle flows and computed changes of surface topography by employing a Galerkin-spline finite-element method. We applied the models to a number of basins of the East European and Siberian platforms. To construct adequate models of basin evolution, we also studied subsidence history of these regions on the basis of a considerable geological and geophysical evidence.

EFFECT OF LATERAL VISCOSITY VARIATIONS IN THE UPPER MANTLE ON DYNAMICAL GEOID PREDICTIONS

M. Klika and O. Čadek (Department of Geophysics, Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00 Praha 8, Czech Republic)

Several papers have recently shown that the effect of lateral variations in viscosity (LVV) on the long-wavelength geoid is small compared with the effect of radial variations in viscosity. Our study basically confirms this conclusion for the viscosity variations in phase with densities but shows that the role of LVV may be significant if the density and viscosity fields are not correlated. This is especially important for the upper mantle where the large-scale viscosity pattern predominantly reflects the distribution of continents and oceans (Ricard et al., JGR 1991), while the density anomalies are mostly associated with the plate boundaries. Assuming a viscosity one order of magnitude lower below oceans than below continents we demonstrate that the amplitudes of the dynamical geoid predicted at degrees 2-12 may significantly change in comparison with the case without LVV. The LVV mainly influence the shape of the geoid spectrum, where the power at individual degrees may be unevenly changed by a factor of 0.5-3. This indicates that the spectrum of the observed geoid could be used as a constraint on the main features of the upper mantle viscosity structure. The prospects of the inverse problem are discussed.

Essential Ingredients for Generating Fast Plumes in the Upper-Mantle: The Case of non-Newtonian rheology versus Temperature-Dependent Rheology

Tine.B. Larsen (Danish Lithopshere Center, DK-1350 Copenhagen K Denmark)
David A. Yuen (Dept. of Geology and Geophysics and Minnesota Supercomputer Institute, Univ. Minnesota, Minneapolis, MN 55415-1227, U.S.A.)

Most of our ideas concerning fast mantle plumes have been ingrained with the notion gained from laboratory experiments of starting plume models using temperature-dependent viscosity.The rheology of the upper-mantle is probably non-Newtonian with an inverse square dependence of the stress on the viscosity. We have studied various rheologies for the generation of plumes besides the proverbial temperature-dependent viscosity. In a series of high-resolution two-dimensional numerical simulations, in which the lateral and vertical resolutions are less than 2 km for the upper mantle, we have found that the vertical velocities in rising plumes are very much faster for a non-Newtonian temperature-and pressure-dependent rheology than for a Newtonian temperature- and pressure-dependent viscosity at similar effective Rayleigh numbers. The peak velocities for non-Newtonian rheology are at least an order of magnitude faster than for Newtonian rheology.

RELATIONSHIP BETWEEN MELT SEGREGATION, PHASE TRANSFORMATION AND VERTICAL MOVEMENT IN UPPER MANTLE

L.I. Lobkovsky (Institute of Oceanology, Russian Academy of Sciences, Krasikova 23, Moscow 117851, Russia, 7-095-124-5990; e-mail: leopold@geo.sio.rssi.ru

New physical model of lithosphere subsidence due to phase transformation of magmatic lens in upper mantle recently was developed to explain the origin and evolution of some large sedimentary basins. The model is based on the following principal assumptions: 1) extension of the lithosphere or mantle plume results in decompression of the asthenosphere,causing partial melting and advection of two-phase material to the base of the thinned lithosphere; 2) the buoyant magma vertically filtrates through the visco-deformable crystalline skeleton; 3) the lithosphere-asthenosphere boundary prevents further rising of the magma, leading to its concentration as a magmatic lens in the upper part of an asthenospheric bulge. The subsequent evolution of this geodynamic system depends on whether magmatic liquid remains within the lens after completion of the extension (or following mantle plume activity) or whether it penetrates the crust and reaches the surface. The first case corresponds to magma consolidation (due to general cooling of the system) into deep eclogite mineral facies and high density eclogite lens formation below the lithosphere leading to its subsidence and the formation of a deep sedimentary basin. The second scenario can lead to the formation of a flood basalt province or a volcanic rift system without noticeable subsidence or even uplift.

MANTLE UNROOTING IN COLLISIONAL SETTINGS

A.M.Marotta , M.Fernandez (Inst. of Earth Sciences "J.Almera" - CSIC - Lluis Sole' Sabaris s/n 08028 Barcelona, Spain)
R.Sabadini (Dept. of Earth Sciences - Section of Geophysics - Universita di Milano, via L.Cicognara 7 20129 Milano, Italy).

A numerical model was carried out to study the thermo-mechanical evolution of the lithosphere under a convergence regime in order to define the conditions that could lead to lithospheric mantle breakoff and consequent unrooting.
We considered a bi-dimensional finite element model where a lithospheric layer and an upper mantle layer are defined. The system is not closed and horizontal flow through lateral boundaries is permitted. A horizontal velocity is imposed at the top of the model to simulate compression whereas velocity vanishes at the botton of the model. The initial conditions correspond to an unrooted lithosphere with heat production in the crust. Different rheologies are considered.
The flow induced in the asthenosphere by the growing lithospheric root and its sinking into the mantle is analysed. Variations in effective strain rate, effective stress, maximum shear stress and kinematic energy are used to determine the possible location and the time of initiation of mantle breakoff.

Tectonic Process as a Consequence of Superposition of Gravitational and Thermochemical Factors

Medvedev N.I., Lab. of Geomechaniks, Institute of Marine Geology & Geophysics, Yuzhno-Sakhalinsk, 693002, Russia

The tectonic processes in the Earth's crust and upper mantle are influenced by the following factors.

1. Gravitational Factor: It is the most important factor which is responsible for all geodinamic processes and it determines P-T condition inside the planet.

2. Thermochemical Factor: It depends upon the gravitational factor. The distibution and change of phase and matter conditions inside the Earth are connected with this factor.

3. Outside Factor: The influence of lunar and solar tides which are some kind of "trigger mechanism" for relieving of stress in lithosphere and therefore giving the definite trend to the tectonic processes as well as promoting conservation of global system of breaks. The tectonic processes in the Earth's crust and the upper mantle fully depend on displacements of heterogeneities in the Earth's depths caused by gravitational differentiation of the matter. These differentiations are some space-and-time fluctuations of density, temperature and chemical composition and they are submitted to the laws of statistic physics. Due to their compexity these processes are not surrended to mechanical interpretation. However, many regularities and mainly the trend of these processes can be explained using probability-and-energetic approach, general laws of conservation and balance of matter and energy as well as surface phenomena in the Earth's scale.

INFLUENCE OF CRUSTAL HEAT PRODUCTION ON THIN SHEET LITHOSPHERIC MODELS

Ivone Jimenez Munt and Manel Fernandez
Institute of Earth Science, Lluis Sole y Sabaris s/n, 08024 Barcelona, Spain

Thin viscous sheet models have been widely used to model the deformation of the lithosphere under plane stress conditions. The averaged lithospheric strenght mainly depends on the Argand number and the Moho temperature once the rock mantle parameters 91n 92 (stress exponent in the rheology) and 91Q 92 (activation energy) are fixed. Up to date however, these models have not incorporated the crustal radiogenic heat production which, in average, accounts for 40% of the surface heat flow. In this communication, we present a numerical analysis on the role of heat production in thin sheet models. Three end member models are considered: a) An initially homogeneous lithosphere which is deformed by an indenter that moves at constant velocity. b) An initially heterogeneous lithosphere -i.e. variations in crustal thickness- which is deformed by applying a constant velocity to the lateral boundary. And c) an homogeneous lithosphere with lateral variations in he at production. The results show that the influence of heat production, within the crust, is noticiable. Deformation is concentrated in areas of larger heat production since viscosity primarily depends on the Moho temperature.

3-D DYNAMIC MODELLING OF SUBDUCTION AND CONVERGENCE IN THE CENTRAL MEDITERRANEAN

A. M. Negredo, R. Sabadini and C. Giunchi (Dipartimento di Scienze della Terra, Università di Milano, Sezione Geofisica, Via L. Cicognara 7, I-20129 Milano, Italy)

The present-day tectonics of the Tyrrenian-Apennine system is controlled by the near North-South convergence between African and Eurasian plates and by the West-dipping subduction of the Adria-Ionian lithosphere. We have developed a 3-D dynamic model to quantify the effects of both convergence and subduction. The axis of the model extends from Sicily to the Alps along the subduction hinge line. We have considered a depth of the slab of 500 km in the southern part of the model and 90 km in the northern area. A convergence rate of 1 cm/yr parallel to the subduction hinge has been applied to the Tyrrenian block. The density contrasts within the slab cause gravitational sinking and roll-back of the slab. Modelling results indicate a gradual decrease of roll-back velocity from South to North, with values ranging between 8 and 2 mm/yr. This decrease is consistent with the arcuate geometry of the subduction hinge. Lateral extrusion due to convergence accounts for the 50 % of the calculated roll-back velocity in the southern Tyrrenian, and is responsible for the overthrusting of the Tyrrenian block over the Adriatic. The pattern of vertical velocity along directions perpendicular to the hinge, with subsidence in the foredeeps and uplift at the border of the overriding plate, is mantained along the whole Italian peninsula, in agreement with observations, but with higher values in the southern areas.

THE EFFECTS OF MANTLE STRATIFICATION ON GLOBAL POST-SEISMIC DEFORMATION

R. Sabadini (Dipartimento di Scienze della Terra, Università di Milano, Sezione Geofisica, Via L. Cicognara 7, I-20129 Milano, Italy)
L.L.A. Vermeersen (Geodetic Institute. Stuttgart University, Keplerstrasse 11, D-70174 Stuttgart, Germany)

The effects of density and viscoelastic stratification on post-seismic deformation due to viscoelastic relaxation in the asthenosphere are quantified by means of a new multi-layered spherical Earth model based on PREM (Dziewonski & Anderson 1981). Our approach follows the normal mode theory with a virtually total analytical scheme, and a new procedure of retrieving the characteristic inverse relaxation times triggered by the discontinuities in the viscoelastic parameters and in the density. The procedure guarantees that all the modes are found with a very high accuracy, irrespective of the amount of layers in which the model is discretized. Both the poloidal and toroidal components are sensitive to mantle stratification. Different Earth models, carrying a various amount of layers, are considered for their impact on post-seismic poloidal and toroidal deformation, both in proximity of the seismic source and in the far field.

THE THERMAL CENOZOIC EVOLUTION MODEL OF THE CRUST OF THE JAPAN SEA

V.V.Soinov*, O.V.Veselov*, A.V.Kochergin*, B.-C.Suk**
* Institute of Marine Geology & Geophysics, Yuzhno-Sakhalinsk 693002, Russia.
** Marine Geology & Geophysics Division, KORDI, Ansan P. Box 29, Seoul 425-600, Korea.

Dynamics of the upper mantle thermal plume influence over the initial continental crust is presented as the model of the chronological sequence of the thermal flashs having the temperature 1400 °C and the duration 1-2 Ma at the depth of 30 km. This sequence is synchronized by the pulse nature of the Cenozoic magmatic manifastations into the Japan Sea region. On the basis of solution of the unsteady thermal state conductivity equation it is shown that between Eocene and Holocene 7-8 "flashs" of the under crust magmatism caused to the temperature change from 500 to 1000–1100 °C at the depth of 28-30 km with the formation of the layer of the partial melting of mafic and ultramafic rocks and the increase of the surface heat flow from 50 to 100–110 mW/m^2. Such transformation of the thermal regime is accompanied by the change of the regional metamorphism from low-temperature, high-pressure facies to high-temperature, low-pressure ones and the reducing of the crust "seismic" thickness from 30 to 18 km. The propositional model is agreed with the observed geophysical data and is conformed to the hypothesis of the formation of the Japan Sea on the base of the continental type.

GLOBAL POST-SEISMIC DEFORMATION: SEARCHING FOR EVIDENCE OF POST-SEISMIC RELAXATION IN ALASKA

G. Soldati and A. Piersanti, G. Spada (Istituto Nazionale di Geofisica, Roma)

Recent investigations based on spherical viscoelastic Earth models have suggested that, in addition to post-glacial rebound and subduction phenomena, post-seismic relaxation due to great Alaska earthquakes could play a relevant role in the assessment of crustal velocity field registered in Alaska using VLBI techniques between 1984 and 1989. The aim of this paper is to test the reliability of this hypotesis by means of a comparison with VLBI data spanning the largest avaliable time-window; in fact, while the rate of deformation associated with post-glacial uplift remain unchanged on such time scales, the exponentially decaying trend of post-seismic displacements, strongly dependent from asthenospheric viscosity, could be discerneable from the detected data. We perform some numerical tests accounting for the presence of an asthenosphere with different viscosity values in order to establish the effective decay rate and its detectability.

DEEP CRUSTAL REFLECTORS BENEATH REYDARFJORDUR, EASTERN ICELAND: CRUSTAL ACCRETION ABOVE THE ICELAND MANTLE PLUME

J.R. Smallwood and R.S. White (Bullard Laboratories, University of Cambridge, UK.)
D. Snyder (British Institutions Reflection Profiling Syndicate,Cambridge, UK.)

Seismic reflection profiling on the Færoe-Iceland Ridge Experiment (1994) imaged a series of dipping events beneath Reydarfjordur, Eastern Iceland. These events dip towards the Northeast Iceland Axial Rift Zone, and continue down to 6 s two-way time, corresponding to a depth of about 18 km.
The 1 km vertical exposures on the sides of the fjord are largely composed of basaltic lavas with some intercalated tuffaceous sediment horizons. New fieldwork in Reydarfjordur has allowed compilation of a composite stratigraphic record of 4 km of the sub-aerially exposed lava sequence. Synthetic seismograms have been computed for the composite section to examine the reflective character of the lava pile. This reflectivity sequence is compared with the FIRE data to test the interpretation that the deep dipping reflections are associated with a dipping sequence of sub-aerially erupted lavas.
Although some existing models of Icelandic crustal accretion can match the observed variation in dip though the exposed lava pile, an interpretation of lava flows buried to a depth of 18 km is problematical. We present a new model of the sequence of crustal accretion on Iceland which is able to explain observed bathymetry and topography, observed lava ages and dip relations and crustal thickness observations across Iceland.

On the role of small-scale convection in formation of lithospheric structures.

E. Timoshkina and V. Mikhailov (United Institute of Physics of the Earth RAS, B. Gruzinskaya 10, Moscow 123810, Russia)

The results presented are based on a mechanical model of the rheologically stratified Earth's outer shell. The model includes the uppermost part of the upper mantle, the asthenosphere, the lithosphere and sediments. The model is asymptotically matched to the model of mantle convection. This provides the relationship between horizontal and vertical component of velocity at the base of the outer shell, as a result only the horizontal one has to be assigned.
We present the results of 2D finite difference modelling of pressure, temperature, density and velocity field evolution within the outer shell of 200 km. thick (the thickness of the lithosphere being 100 km.). During the active stage, extensional (sedimentary basins) and compressional (orogens) areas were formed under influence of uprising and downwarping mantle flows and/or intraplate forces. The model predicts that after external forces ceased, movements within the outer shall did not stopped, but the long-lived small-scale convection in the low viscous asthenosphere developed under the influence of pressure gradients. This manifests in additional extension of the lithosphere of sedimentary basins and compression of orogens, as well as in formation of rift shoulders and foredeeps. Development of these structures, their width, amplitude and rate of subsidence or uplift depends considerably on the style of mantle movements at the active stage; on the thickness of the asthenosphere and on gradient of its density with depth.

THE POSITION OF THE URALS IN EUROPEN-ASIAN STRUCTURES AND GEODYNAMICS

A.M.Vinogradov., B.P.Ryzhi (Institute of the Urals branch Russian Academi, Amundstenstr.100,Ekaterinburg, 620016,Russia), M.S.Rapoport (Urals Geological Committee, Vainerstr.50,620219,Ekaterinburg,Russia)

The morfostructural analysis of geophysical fields of the Urals and neighbouring areas in addition to juxtapositions of received results and theoretical conceptions about furnacing and plum-tectonic courses in development of the Earth have served by base for new hypothesises of the region's origin and deep structure. Authors have proven for the fist time the Western Siberian tectono-magmatic system that formed above mantle superplum which had removed during Paleozoic period more 1000 km in level direction. The plum's moving determined emergence of convecting cells with the formation of tectonic pair which has determined differeces in the development and structure of the Western Siberian and Kazakhstanian parts of the system. The Urals lie in the board of the least desteructural its part. The deep architecture in addition asymmetrical zoneation of the Urals allon to isolate three sectors with different tectonic characteristics and metallogeny of the Earth's crustal units.

ON THE INFLUENCE OF PLUMES ON CONTINENTAL RIFTING

H. Zeyen (Institutionen för Geofysik, Uppsala Universitet, Villavägen 16, S-75236 Uppsala, Sweden)

Many continental rifts are related in time and space to plume activity. However, plumes seem to have an ambiguous influence on rifting which shall be demonstrated with examples from the European Cenozoic and the Afro-Arabian Rift Systems. A small plume was able to trigger extensional deformation in the thin lithosphere of the French Massif Central which is distributed over a wide area above the plume, merging into one single rift further north where the plume influence vanishes. In the East-African Rift System, a large plume seems to have provided the forces for whole-lithosphere extension. Strong variations in the style of rifting of the eastern branch are probably related to prerift variations in the lithospheric thermal regime: linear, concentrated deformation takes place in the cooler southern part, whereas widespread areal (ductile) deformation prevails in the north. The Red-Sea/Gulf-of-Aden Rift System was again triggered by a major mantle plume. Continental break-up occurred north and east of the plume influence. However, it was up to now inhibited above the plume centre due to predominance of ductile deformation in combination with crustal underplating. Although plumes are generally not able to cause major rifting and continental break-up without far-field extension, they may trigger whole-lithosphere deformation which can be in the form of a linear fracture, as seen in cool, strong lithospheres or areally distributed, ductile deformation in preheated areas or above the plume centre.

COMBINED EFFECTS OF LITHOSPHERE THICKNESS AND ENDOTHERMIC PHASE TRANSITION IN THE MANTLE ON PLUME MORPHOLOGY AND DYNAMICS

Shuxia Zhang (St. Anthony Falls Laboratory, University of Minnesota, USA)

Tectonic features on earthlike planets have been simulated using a 3-D spherical model of time-dependent, compressible mantle convection with a lithosphere and an endothermic phase boundary at the depth of 700 km, subject to isothermal free-slip boundary conditions. The lithosphere with a varied thickness is approximated by a high viscosity layer. The most profound influence arising from the endothermic phase change is the geometrical change of upwelling flows which, starting from cylindrical features, gradually become linear hot sheets in the lower mantle and extend laterally more than a quarter of the circumference. The surface flow features are controlled by lithosphere thickness. In the case where no thick lithosphere exists, the hot upwelling sheets can penetrate into the upper mantle and strongly spread near the surface and the downwelling flows are characterized by long cold sheets far away from the upwelling centers. In case of a thick lithosphere ($> 300km$) presented, the upwelling flows near the surface are characterized by pancake-like hot plumes, and the downwellings are cold rings closely around the pancake-like plumes, leading to the topography resembling the Coronae on Venus. The mean temperature of the upper mantle in the latter case is also significantly higher than that in the former case. The results from this study indicate that, if an endothermic phase change also exists in Venus, its thick lithosphere may be the influential factor that renders tectonic features dramatically different from those on the Earth.

SE2 Earthquake source mechanics: new views in the understanding of seismic rupture processes

Convener: Cocco, M.
Co-Conveners: Campillo, M.; Dahm, T.; Spudich, P.

MOVING WAVES OF DEFORMATION AS A MECHANISM OF RUPTURE PROCESS; MASS TRANSFER AND DISPLACEMENT MOTION.

V.V. Aksenov, T. Locaicek and **V.V. Aksenov** (United Institute of Physics of the Earth, Russian Academy of Sciences, Bol'shaya Gruzinskaya 10, Moscow, 123810,Russia)

It is represented a contact interaction of two solid bodies at their relative motion by the scheme of contact interaction of mass-having slender deforming lines. Relationships between relative velocity and motion value of a contact surface arbitrary point and geometrical form of deformation transverse and longitudinal waves, their velocities and contact lengths are reported. Forms of longitudinal and transverse waves at displacement motion are observed on different models. Deformation wave velocity; velocity and value of displacement of a contact surface of arbitrary point in the course of moving wave of deformation are determined experimentally. Theoretically estimated and experimentally observed spectra of oscillations have been presented. Physical interpretation of observed (laboratory experiments, rock bursts, aftershocks) modulated oscillations, in the shape of interaction of elastic waves and deformation ones is given. Physical interpretation of observed on longperiodic waves break as deformation wave is given on the example of the Landers earthquake aftershocks.

ON PROCESSES IN STRONG EARTHQUAKE SOURCE ZONES OF TIEN-SHAN EARTH CRUST

N.Kh.Bagmanova (Institute of seismology, NAS KR,Asanbai,52/1, 720060, Bishkek, Kyrgyzstan)

In these paper were considered the source zones of nine strong earthquakes (M>5), happened in Tien-Shan during 1978-1992. Among them such as: Alai (1978,M=,), Djirgatal (1984, M=5.9), Baisorun (1990, M=6.1), Suusamyr (1992, M=7.3). On the base of small earthquakes mechanizms the character of seismotectonic deforming the earth crust is studied. This character is observed in source zones in preparation period of strong events. It was made comparison between character of deforming, taking place in source during preparation period of strong earthquake and strains originating in earth crust as result of these events. Comparison showed their discrepancy. For North Tien-Shan and South Tien-Shan seismogenerating zones the differences in processes of crustal deforming are noted.

THE REDISTRIBUTION OF DYNAMIC STRESS DURING CO-SEISMIC RUPTURES: EVIDENCE FOR FAULT INTERACTION AND EARTHQUAKE TRIGGERING

M.E. Belardinelli (Istituto Nazionale di Geofisica (ING), Via di Vigna Murata 605, 00143, Rome, Italy)
O. Coutant (LGIT - Observatoire de Grenoble, IRIGM BP 53 X 38041, Grenoble, France)
M. Cocco (ING)
F. Cotton (LGIT)

In this study we investigate the temporal variations of the stress field outside a rupturing extended fault. The dynamic stress variations caused by a coseismic rupture in a layered half-space are computed using the discrete wavenumber reflectivity method (Cotton and Coutant, 1996). The temporal evolution of dynamic stress allows to calculate the final static stress as a function of spatial position. We compare the static stress changes resulting from this model with those resulting by a static dislocation model. We have applied this method to study the interaction among the three fault segments that ruptured together during the 1980 (M 6.9) Irpinia normal faulting earthquake. The first two subevents are separated in time of 20s and the last occurred 40s after the rutpure onset. Rupture did not jump from a rupturing segment to the adjacent one immediately, but the triggering of subevents is delayed by few tenths of seconds. This earthquake provides a unique opportunity to investigate if the subsequent rupture episodes are caused by the dynamic or the static stress changes.

RUPTURE PROCESS CONSTRAINST OF THE M_S = 6.2, 1995 AIGION EARTHQUAKE, USING THE SPECTRAL SOURCE MODEL

C. Berge and P. Bernard (Institut de Physique du Globe, F-75005 Paris. France)

The understanding of rupture processes, high-frequency radiations, directivity effects, and seismic hazard assessment require the estimation of strong motion for any source to receiver configuration and distance.
We present a spectral extented source model, which enables the generation of broad-band accelerograms particularly for stations located very closed to the fault. The $k-square$ dislocation distribution concept (k being the radial wavenumber) of *Herrero & Bernard* [1994] is associated with a propagating finite width pulse and a wavenumber dependent source time function (*Bernard & al.*, [1996]). Then synthetics have the "ω^{-2}" standard radiations and the directivity effects are correctly taken into account.
We illustrate the efficiency of the model and the absence of numerical singularity on the M_S = 6.2, June 15, 1995 Aigion (Greece) earthquake, which provided several near source accelerograms evidencing of strong directivity effects, in duration and amplitude signal terms and damage distribution. We show the interest of the model to constrainst the rupture process complexity and to predict strong ground motion.

RECENT SEISMIC ACTIVITY IN REGION OF INTENSIVE OIL RECOVERY (TATARSTAN, RUSSIA)

M.Ya.Borovskyi, N.Ya.Shabalin, Yu.B.Antonov, D.K.Nurgaliev, A.I.Shevelev, I.H.Kaveev, G.E.Kuznetzov, P.V.Vishnevskyi (Faculty of Geology, Kazan University, 420008, Kazan, RUSSIA)

In recent time seismic security in Republic Tatarstan (RT) is especially considered because of increasing seismic activity conditioned by either endogene or technogene factors. In RT seismic vibrations for 4-6b occure in stressed zones. Since 1980th the number and strength of earthquakes increased in S-Eastern and N-Eastern parts of RT (~300 earthquakes, including ones of 5-6b by scale MSK-64 for 1984-1994). Almetevsk earthquake (28.10.1991) belongs to high energetic class (K=10). It was accompined by intensity of vibrations in epicentral zone to 6b. The squares of 5b vibrations of this earthquake and preceding one (23.09.1986, K=10.6) are more than 500km² and 300km² respectively. It is not excluded the possibility of more strong earthquakes in the East of RT(K=11-12, magnitude M=4-4.5), that on depths 5-7 km of their centres and on weak soils, can induce epicentral seismic intensity to 7-8b. Therefore, in RT it is actual the problem of increasing of recent seismotectonic activity in result of technogene factors after oil fields development (injection of water, chemicals, heating and combustion of bitumen reservoirs, karst processes, etc.).

IMAGING THE RUPTURE PROCESS OF THE 1995 KOBE EARTHQUAKE FROM S-WAVE POLARIZATION ANALYSIS

M.P. Bouin (Department of Earth Sciences, Parks Road, Oxford, OX1 3 PR, U.K.)
M. Cocco, G. Cultrera (Istitute Nazionale di Geofisica (ING), Via di Vigna Murata 605, 00143, Rome, Italy)
K. Irikura and H. Sekiguchi (Disaster Prevention Research Institute, Kyoto University, Japan)

We investigate the high frequency (f>1Hz) rupture process of the 1995 Kobe earthquake by analysing the S-wave polarisation of near-source ground motion recordings. We selected the 10 closest stations to the fault plane in order to extract information on the rupture history. Firstly, we explain part of the unstability of the S-wave polarization with the presence of shallow crustal anisotropy in the Kobe area. Our results in terms of anisotropy parameters are in good agreement with those of anisotropy study performed in the same area by Japanese authors. The time variation of the corrected S wave polarisation is then interpreted in terms of the successive radiation by different sub-sources. The assumption of a uniform strike-slip mechanism on the fault plane allows us to model the northwestward propagation of the rupture. We test the influence of a thrust component in the mechanism. We constain the spatial and temporal domain for 2 high frequency subsources. We compare and discuss our results with models deduced from low frequency analyses. Our results demonstrate that S-wave polarisation contains powerful information on the details of the rupture history.

SEISMIC SOURCES OF EARTHQUAKES IN PERU

H. Tavera and E. Buforn (Dept. de Geofisica, Univ. Complutense, Madrid)

Focal mechanisms of 10 earthquakes (5.9<M<6.5) occurred in Peru between 1990-1996 have been studied using wave from analysis. Five events are located at shallow depth (h<40 km), four are at intermediate depth (40<h<350 km) and one at very deep depth (h=569 km). Fault-plane orientation have been estimated from first motion of P-wave using stations at regional and teleseismic distances. Source time functions depth and scalar seismic moments are obtained from modelling body waves recorded at teleseismic distances. Most of shallow earthquakes show very complex rupture proccess, with predominant reverse faulting mechanisms and horizontal pressure axis oriented in NE-SW direction. Results for earthquake of 04/05/91 and 02/21/96 they are caused by a complex rupture formed by 3 events. For the first with similar depth and mechanisms of fault inverse and the second with similar mechanisms and depth of 8,16 and 21 km. Results for intermediate depth earthquakes show simple source time functions and mechanisms that correspond mostly to normal faulting. The very deep depth earthquake (01/10/94, h=596 km) presents also a mechanism of normal fault with a vertical plane oriented in E-W direction and pressure axis dipping about 45° to NW. For this shock, source time function has been estimated from modelling direct P and SH phases and from deconvolution with the instrument of P, pP and sP phases, with similar results. Scalar seismic moments and dimensions for all shocks have been estimated from modelling body waves and from spectral analysis, with total agreement.

A Mechanism of Strong Earthquake Foci Generationof the North-Western Pacific

Burymskaya R.N., Institute of Marine Geology & Geophysics, Farastern Branch of Academy of Sciences, 693002, Yuzhno-Sakhalinsk, Russia

A process of a spontaneous disturbance of solid medium of crustal and upper mantle elastic-deformed volume, accompanied by the study of seismic wave radiation, is an earthquake source. Using K.K. Zapolsky's CHISS-analysis the process of seismic radiation is studied as a spectral-temporal function of the source. Strongest earthquakes of the Kuril-Kamchatka and Japanese (partially) regions for 1969-1983 were processed.

Both qualitative and quantitative differences between the strongest and stronger events were revealed. It was shown that a mechanism of generation of the strongest shocks is stronger. Their development is more durative and occurred by stages. Such multiplex earthquakes are characterized by low-frequency radiation, low-velocity (average) of fault motion, durative growth of maximum radiation.

CHARACTERISTIC LENGTH AND TIME OF GROWTH DURING THE INITIATION OF INSTABILITY UNDER SLIP DEPENDENT FRICTION

M. Campillo (Laboratoire de Géophysique Interne, Observatoire de Grenoble, 38041 France)
I.R. Ionescu (Laboratoire de Mathématiques, Université de Savoie, 73376 Le Bourget-du-Lac, France)

We study the initiation of an unstable anti-plane elastodynamic shear process under slip-weakening friction using an eigenvalue analysis. Considering only the part of the solution associated with positive real eigenvalues, we define a 'dominant part' characterized by an exponential growth with time. The analytical expression shows that in response to a small initial perturbation on the fault or in the medium, the instability will develop in a limited spectral domain. The limiting wavenumber (or reciprocal critical length) is a function of the parameters of the friction law and the elastic properties. Crack-like propagation will begin when a critical slip is reached. According to our analysis this slip cannot be reached unless the patch is larger than the critical length. After the application of a perturbation and the development of an instability, the slip reachs its critical value after a time which can be computed analytically. Several applications will be presented.

MOMENT TENSOR INVERSION FOR SEISMIC SOURCES WITH FINITE EXTEND

T. Dahm (Institut für Meteorologie und Geophysik, Universität Frankfurt am Main, D-60323 Frankfurt am Main, Germany)
F. Krüger (Seismologisches Zentralobservatorium GRF, Krankenhausstr.1-3, D-8520 Erlangen, Germany)

The finite spatial and temporal extend of seismic sources can be approximately taken into account by keeping the first two order moment tensors in a Taylor expansion of the Green's functions around a spatial and temporal point. The inverse problem is then to estimate 90 source parameters representing the extended source. We follow the approach of Doornbos (*GJR 69, 1982, 235-251*) and introduce smoothing assumptions to reduce the inverse problem to the estimation of 20 source parameters. One crucial step for the inversion is to calculate corresponding higher order spatial derivatives of Green's functions, which we solved by using a reflectivity ansatz. We show that the relevant far field Green's functions in layered media can be synthesized from five elementary integration kernels multiplied by vertical and horizontal slownesses. The nonlinear inversion problem is linearized and solved with an iterative procedure starting from the usual moment tensor solution. We present examples with synthetic data and present first applications.

HOW FAR CAN REGIONAL AND GLOBAL INVERSIONS FOR SOURCE MECHANISMS DESCRIBE THE SOURCE ?

H. Dufumier (Ecole et Observatoire de Physique du Globe, 5 rue R. Descartes, 67084 Strasbourg Cedex, France)

Two methods devoted to the detailed description of source processes, from inversion of local complete high-frequency seismograms, have been extended to the european scale. The first one (Sileny, Panza and Campus, 1992, Geophys.J.Int., 109, pp 259-274) inverts in a first step for a time-variable moment tensor, 3D hypocenter relocation and structure refinement, then for average moment tensor and source time function. The second one (Mao, Panza and Suhadolc, 1994, Geophys.J.Int., 116, pp 784-798) is a non linear inversion for double-couple, source time function and 3D hypocentral relocation. In both cases, source time functions are parametrized by a serie of triangles, and therefore the number of parameters to be inverted depends mainly on the complexity required to describe the source history. With the help of some inverse methods tools such as the condition number, the resolution matrix and the cost function mapping, we draw some conclusions on the ability of such methods to determine various source parameters such as the mechanism, the isotropic component, the hypocentral relocation, the source history and the rupture directivity, both at the local - high frequency scale and at the regional scale. An application of the regionally - extended inversions is shown for the case of the Roermond (April 1992) earthquake. Comparisons are also made with the limits of teleseismic moment tensor inversions of long period surface waves (Dufumier and Cara, 1995, PAGEOPH, 145, pp 235-257) and body waves (Dufumier, 1996, PAGEOPH, 147, pp 467-482).

SEISMIC BEHAVIOUR OF A TECTONIC STRUCTURE IN A VOLCANIC AREA: AN EXAMPLE FROM MT.ETNA, SICILY.

S. Gresta and F. Ferrari (Istituto di Geologia e Geofisica, University of Catania, C.so Italia 55 - 95129 Catania, Italy)
F. Bianco and M. Castellano (Osservatorio Vesuviano - Napoli, Italy)

Several geo-structural and geophysical studies have identified an important structural element on the northeastern side of Mt. Etna volcano: the "Pernicana fault". From 1981 to 1988 it has been one of the most seismically active fault in the whole Eastern Sicily. We performed waveform analysis of the microseismic activity which occurred during 1994-1996 along the fault by using data from a temporary digital seismic array deployed just over the fault. Several doublets and multiplets have been recognized. They present very similar waveforms and differences in time arrivals of P and S waves, and identical "particle motions" and spectra. This suggests a jerky propagation of the rupture along the fault, involving seismogenic sources 40-100 m long, few hundreds of meters deep.

AN ESTIMATE OF STRESS RATE IN LOS ANGELES FROM AN ANALYSIS OF NORTHRIDGE AFTERSHOCKS

Susanna J. Gross (CIRES, University of Colorado, Boulder, CO, 80309, USA)

A model of the static stress change associated with the Northridge mainshock has been fit to the change in the spatial distribution of seismicity in order to derive a background stress state. I used a source model provided by David Wald and the Caltech-USGS catalog of earthquakes. The best-fitting background stress state is similar to a stress state inferred from focal mechanisms, but it also contains some information on the magnitude of the maximum compressive tectonic stress ≈ 1.5 MPa, effective overburden, and fault friction. Using Dieterich seismicity theory to interpret comparisons of the rate of aftershocks with the rate of background earthquakes provides an estimate of the tectonic stressing rate, $\approx 2-3$ Pa/day. The stress rate is significantly less than would be expected on the basis of strain observations, and suggests that ductile processes may be active at seismogenic depths below the Los Angeles basin. The low coefficient of friction, small background stress magnitude, and little effect of overburden pressure found in the stress state inversion are also consistent with the presence of lithostatic pore fluids or ductile processes influencing the stress field.

INFERENCE OF ABSOLUTE TECTONIC STRESS FOR THE 1995 KOBE, JAPAN, EARTHQUAKE

Mariagiovanna Guatteri (Dept of Geophysics, Stanford Univ., Stanford, CA 94305 USA)
Kenshiro Otsuki (Dept of Geoenvironmental Sciences, Tohoku Univ., Sendai 980, JAPAN)
Paul Spudich (USGS MS977, Menlo Park, CA 94025 USA)

Dislocation models of the 1995 Kobe earthquake, derived by Ide et al. (submitted, BSSA, 1996), Wald (submitted JPE, 1996), and S. Yoshida et al. (submitted JPE, 1996) all show substantial changes in direction of slip with time at specific ponts on the fault, as do striations observed on exposed fault surface on Awaji Island. Using the construction of Spudich (Tectonophysics, 1992) we have estimated the tectonic stresses consistent with these temporal rake rotations. Ide's and Wald's models are generally not consistent with any absolute tectonic stress, whereas many subfaults in Yoshida's model are consistent with about 10 Mpa tectonic stress. Yoshida's model is also more consistent with observed surface slip than are the other models. If Yoshida's model is correct, it suggests that the Nojima fault slipped at very low shear stress, and stress drop was almost complete. However, the inference of absolute stress level is strongly dependent upon our assumed errors in the slip models.

TEMPORAL VARIATION IN STRESSES IN SW JAPAN ON THE BASIS OF A KINEMATIC BLOCK-FAULT MODEL OF GEODETIC DATA

M. Hashimoto (Geographical Survey Institute, Kitasato-1, Tsukuba, Ibaraki 305, JAPAN)

We simulate temporal variation in stresses in southwestern Japan on the basis of block-fault model by Hashimoto and Jackson (1993). We use their estimate of slip deficit rates of block boundary faults to calculate accumulation of Coulomb failure function (CFF) since 1855, just after the great Ansei earthquakes. We also calculate changes in CFF due to large (M>6, if possible) earthquakes by using their published fault parameters. In this paper, we examine whether CFF which promotes rupture of inland events such as the 1995 Kobe Earthquake was increased or not before the event. This calculation shows CFF in the source region of the Kobe EQ was increased by the accumulation of slip deficit of nearby block boundary faults, not by that of faults between the subducting Philippine Sea and overlying plates. This rejects the hypothesis that increase of coupling between these two plates before the great Nankaido events would stimulate the activity of inland earthquakes in southwestern Japan. Some inland earthquakes, except 1927 Tango, also promoted the occurrence of the Kobe EQ.

DETERMINATION OF CONSTITUTIVE RELATIONS BASED ON SEISMIC WAVE ANALYSIS FOR THE 1995 KOBE, JAPAN, EARTHQUAKE.

S. Ide (Earthquake Research Institute., University of Tokyo, 1-1-1, Yayoi, Bunkyo, Tokyo, 113, JAPAN), M. Takeo (ERI, Univ. of Tokyo)

Constitutive relation is the boundary condition on fault plane and governs many aspects of earthquake failure. Although several constitutive laws have been formulated based on laboratory rock experiment, no actual relation during natural earthquake is obtained. The 1995 Kobe earthquake is suitable for detailed kinematic analysis because many near-field strong motion records are available, and this enables the first evaluation of constitutive relations of natural earthquake. In this study, I determine spatio-temporal slip distribution on an assumed fault plane by waveform inversion, and then, solve elasto-dynamic equations by finite difference method to determine stress distribution and constitutive relation between slip and shear stress on the fault plane. An inversion method based on Bayes Theorem is employed to obtain a spatio-temporal slip distribution to ensure the objective uniqueness of the solution with numerous parameters and smoothing constraints. The slip distribution is then used as part of the boundary condition in the finite difference calculation. The obtained time histories of slip and shear stress provide a constitutive relation, showing slip-weakening almost everywhere on the fault plane. They also show a clear depth dependency indicating that the slip-weakening rate is smaller and/or critical slip-weakening displacement is larger in the shallow crust. This may be associated with the paucity of shallow seismicity observed in the source region of this earthquake.

NUMERICAL SIMULATION OF ANTIPLANE SHEAR WITH SLIP DEPENDENT FRICTION : INITIATION AND PROPAGATION

I.R. Ionescu (Laboratoire de Mathématiques, Université de Savoie, 73376 Le Bourget-du-Lac, France)
M. Campillo (Laboratoire de Géophysique Interne, Observatoire de Grenoble, 38041 France)

We study the initiation of an unstable anti-plane elastodynamic shear process under slip-weakening friction. We show the accuracy of the theoretical analysis by comparison with numerical tests computed with an independant technique. These tests were obtained by using a numerical approach of the nonlinear problem. After splitting, an alternating direction method is used to reduce the problem to two hyperbolic systems in one space-dimension, for each time step. A classical finite difference scheme (Lax-Wendroff) is used in the discretisation of these systems. For the nonlinear boundary condition we used the integration along the characteristic lines to deduce an instability capturing scheme. Rapidly after the initial perturbation and during all the initiation phase, the dominant part governs the time and space evolution of the slip until the critical slip has been reached at some point of the surface. For large times, seismic rupture front tends to propagate at the shear wave velocity but it is delayed with respect to the wave emitted at the initial perturbation. Between the steady state propagation of the rupture and the initiation phase, a transition phase exists characterized by an apparent supersonic velocity of the rupture front. This phenomenon occurs because the critical slip is reached almost simultaneously on a patch of finite critical length.

THE LOW FREQUENCY SIGNAL AND TIME EVOLUTION OF THE SEISMIC MOMENT

V.V.Ivanov (Institute of Marine Geology & Geophysics Y.Sakhalinsk Russia)

There are discussed the observations of earthquake 12.7.93 at Japan Sea. There are analyzed the seismic records IRIS system on the station YSS (47 N,142.75 E),MAJO(36.3 N,138.1 E),MDN(44.36 N,129.5 e), by using the smoothing with interval 1 and 2 min. These stations located on the distances less than 1000 km from the source. The analysis shows that the records contain two outstanding signals .The first come together with surface wave, second come with delay 160 min. The first signal has a duration near to 17 minutes. The signals are interpreted as a result of action of time depended seismic moment applied to the epicenter.The time dependence of the different components is calculated by using the low frequency seismic records. The calculation show that the process of the earthquake develops during the 17 minutes and the fault plane location changes during the process 3 times . The stretch line of the first and third planes coincided with stretch line of tsunami source. The second and fourth planes stretched at perpendicular direction.

LABORATORY ANALYSIS AND MODELING OF HEALING AND LITHIFICATION IN SIMULATE D FAULT GOUGE

S. L. Karner and C. J. Marone (both at: Dept. of EAPS, MIT, Cambridge, MA, 02139)

We report on hold-slide, slide-hold-slide, and velocity-stepping experiments involving gouge layers sheared within Sioux Quartzite in a triaxial pressure vessel at elevated pressure (P_c=250 MPa), elevated temperature (230 – 636°C), and in the presence of water (P_f=75 MPa). Samples from hold-slide experiments healed at 636°C and deformed at 230°C show increasing peak and stable-sliding friction with healing time ($\mu_p \approx 0.1$ and $\mu_{ss} \approx 0.08$ per decade change in t_h). Samples healed and deformed at 636°C showed lower peak strengths where μ_p and μ_{ss} did not increase significantly with t_h. Data from slide-hold-slide experiments show relaxation during the holds. Minimum friction (μ_{min}) decreased linearly with the log(t_h) (-0.092 per decade change in t_h). Upon reloading, friction increased to a new stable-sliding value without a distinct frictional peak prior to stable slip. The reload μ_{ss} values are typically lower than the μ_{ss} before the hold. We have modeled the: 1) slide-hold-slide experiments; 2) healing rates; and 3) velocity-stepping experiments; using different rate- and state-variable friction constitutive laws (Dieterich, Ruina, and Perrin-Rice-Zheng laws). The model inversions of the data indicate velocity strengthening behavior with (a-b) values between 0.05-0.10, and a negative effective state-evolution term "b". Predicted fits to the data using the Dieterich law, and based on the friction parameters from the model inversions, show μ_{min} decreasing at -0.105 per decade change in t_h comparable to the observed μ_{min} decrease.

COULOMB STRESS INTERACTIONS BETWEEN FAULTS. WE SEE STRONG EFFECTS BUT WHY?

Geoffrey King, Aurelia Hubert, Eric Jaques, IPG de Paris, 4 place Jussieu, 75252, Paris, Cedex 05 France. king@ipgp.jussieu.fr
Suleyman Nalbant, Istanbul University, Engineering Faculty, Geophysics Department. 34850 Avcilar Istanbul, Turkey.

Over the last few years it has become clear that both aftershocks and subsequent larger events are controlled by Coulomb stress changes due to major events. Examples are shown for the Western USA, the Aegean region and Afar. Coulomb interaction provides a powerfull method for identifying regions of raised long term seismic risk and is consequently of major practical importance. That an earthquake should be related to previous ones by the stresses they have created seems straight forward. It is not, and numerous critics have declared that it can't possibly work because the stresses are too small. Even stress changes less than 1 bar seem to be significant. Their objections are not unreasonable. It seems likely that the apparent simplicity of the Coulomb formulation conceals more complicated underlying physics that we do not yet understand. Many questions can be asked, but have not yet been answered. Are the events actually triggered or do Coulomb stress changes simply allow events that would otherwise occur to propagate more readily? Why do dynamic stresses due to seismic waves or tides not trigger events? How do stress systems evolve with time following an earthquake? What is the role of multiple faulting in the brittle crust?

THE POSSIBLE SEISMIC ACTIVITY MECHANISM

Iudin D.I., Kas'yanov D.A.,(Radiophysical Recearch Institute, 25/14 Bolshaya Pecherskaya str., Nizhny Novgorod, 603600 Russia)

The report presents new idea of the seismogenesis. The idea shows the lithospherical substratum as a solution containing light admixture. This substratum-solution and gravitational field of the planet form the system with an activity. The mechanism of activity is bound up with satiety of the solution and possible light admixture isolation as the independent thermodynamical phase. It is shown, the increase of the light phase specific volume makes the effective strengthening of the inter-phases stress field. The necessary for destruction changes arise when the connectivity of the light phase appears on those scales which exceed critical radius. Critical radius is defined like ratio between durability of the firm phase and the gravitation. The description of the substratum behaviour when the light phase specific volume changing is given in terms of the percolation theory. Also, the report presents some model experiments which confirm the idea.

D.I.Iudin, Radiophysical Recearch Institute, 25/14 Bolshaya Pecherskaya str., Nizhny Novgorod, 603600 Russia, Fax:8312-369909
Session SE2 Earthquake source mechanics: new views in understanding of seismic rupture processes
Convener: M.Cocco
Standart equipment. Preference for oral.

THE SHOCK-WAVE MODEL AS A EARTHQUAKE MECHANISM

V. V. Kuznetsov and V. V. Kuznetsov (Institute of Geophysics, University av..3. Novosibirsk 630090, Russia)

The main idea of the new model of the earthquake mechanism is that under the effect of the external loading the heavily cracked medium arises in the lithosphere. Synchronously with arising the cracks, the spring (elastic) acoustic wave (sound impulse) arises which propagating in the heavily cracked medium causes the new crack formation and so on. The acoustic wave in such a medium can (become stronger) increase up to its transfer into shock-wave. This wave propagates in the lithosphere. goes out on the daily Earth's surface, reflects from this surface and again goes deep into lithosphere. In doing so the tension (unloading) wave arises which causes the surface destriction. that is the earthquake cause.

THE RATE OF FAULT HEALING: LABORATORY STUDY OF THE EFFECT OF SLIP VELOCIT Y

C. Marone (Dept. of EAPS MIT, Cambridge, MA, 02139, USA)

The seismic cycle of repeated instability requires that faults restrengthen (heal) during the interseismic period. The rate of fault healing plays a key role in determining fault strength, seismic stress drop, and the mode of dynamic rupture propagation. Laboratory measurements indicate that friction increases approximately linearly with log time during quasi-stationary contact, which is consistent with some seismic estimates of fault healing. However, in the laboratory rock friction increases by only a few percent of its absolute value per decade in time, whereas seismic stress drop increases by a factor of 2-5 per decade increase in earthquake recurrence interval. The discrepancy may be due to differences in laboratory and field conditions or limitations in the database of interseismic healing. However, previous comparisons have not recognized the effect of initial sliding velocity on fricti onal healing. I present laboratory measurements showing that static friction and the healing rate of simulated faults vary with the velocity of sliding prior to quasi-stationary contact. The experiments show a trade-off between healing time and initial slip rate, with faster slip producing larger static friction for a given
time. Since seismic slip rates are generally 0.1 to 1 m/s, whereas laboratory measurements have been made at 10^{-6} to 10^{-5} m/s, the present data are important for understanding the descrepancy between laboratory and seismic estimates of fault healing. Also, the data have important implications for models of self-healing rupture, which require rapid healing in the region just behind the rupture tip.

A mechanistic explanation for fault zone heterogeneity and the weakness of faults

S.A. Miller, Geology Institute, ETH-Zurich, Switzerland

An unresolved problem in earthquake source physics is a mechanistic explanation for the dual observations that many major plate bounding faults are weak, and that a large degree of fault zone heterogeneity is required to recover the Gutenberg-Richter magnitude frequency relationship. A preferred explanation for the weakness of faults is elevated fluid pressures within the fault zone, while the GR statistics can be obtained by a self-organizing dynamical system. A recently developed fluid-controlled fault model that couples evolutionary fluid pressures with shear stress accumulation from plate motion satisfies both these requirements of an earthquake model, and appears to capture many other important aspects of the physics of faulting. The model is driven by a time-dependent porosity reduction (or fluid source) mechanism, which increases pore pressures within discrete impermeable cells at rates that depend on the porosity or the pore compressibility. Increased fluid pressures allow slip at low effective stress, and when a slip condition is reached, shear stress is redistributed within the fault plane using elastic dislocation theory. Dilatancy accompanies slip, so fluid pressures are reduced in the slipped cell, and thus provide a natural healing mechanism and a reasonable explanation for repeated events. According to the model, the system evolves from an initially uniform stress state in Mohr-space (with all cells far from the simple friction slip condition) to a state where a wide range of conditions exist. The evolved complex state in Mohr-space produces rupture patterns that include stress drops ranging from 1-100 MPa (with most in the 1-10 MPa region), and variable slip patterns for individual earthquake events. The model shows that the evolved state of shear stress persists (thus maintaining a large degree of fault zone heterogeneity) while the pore pressure state tends to homogenize at an elevated pore pressure. This behavior will be discussed, in addition to asperity development and destruction which evolve naturally within the model.

CASCADE EARTHQUAKES IN ALBANIA

B.Muço (Seismological Institute, Tirana, Albania)

A complex web of active faults is distributed throughout all the territory of Albania. The intersection of the northwest-trending Adriatic and Ionian longitudinal fault system and northeast-trending shear fault systems, dominates Albanian tectonics and gives rise to recent seismic activity backed mostly by the confrontation between Adria microplate and Albanian orogen.
Sometimes, activation of some active fault produces the earthquake activity in a neighbour one and this process could continue as a cascade through other faults. This may cause the migration of seismic activity from one system of faults to another and sometimes could lead to wrong deduction about the proper fault responsible for an earthquake.
Based on the available data from the records of Albanian Seismological Network, since 1976, some cases of the so-called cascade earthquakes for Albania are evidenced in this approach trying to explain also their mechanism.

STRESS CONCENTRATION, FRACTURE AND GENERATION OF ELASTIC WAVES

M.Nemirovich-Danchenko (Tomsk Department of the United Institute of Geology, Geophysics and Mineralogy. P.O.Box 2282, 634055 Tomsk, RUSSIA)

Earthquake source was considered as an act of energy release at a crack growth. The problem was solved using continuous mechanics approach. Complete system of continuous mechanics equation were used in Lagrange variables: motion equations, equations of state, equation of energy balance, equation of contituity. The equations of state were completed with flow condition. It allowed to carry out the calculations for both elasto-brittle and elasto-plastic states. The discrete analogue was build up using the splitting of the net nodes, that allowed to calculate the fracture of initially continuous solid body. A number of numerical experiments was performed: 1) the medium with a crack is quasi-staticaly loaded with slowly increased load (extension and spalling); 2) at the crack tip the stress is gradually concentrated; 3) when the fracture criterion is reached near the crack tip, the crack abrupt growth take place; 4) the crack jump is characterized by appearance of new free surfaces that leads to enefry release as the elastic waves (this is the very act of wave generation in the model). The loading conditions and presence of stress concentration were shown to define the character of the generated perturbation anf to change the medium where the perturbation is propagated. The calculated data are presented in vector fields and seismograms.

STRESS FIELD CHANGES CAUSED BY POSTSEISMIC RELAXATION: AN APPLICATION TO STUDY THE STRESS TRANSFER BETWEEN SEISMOGENIC AREAS

C. Nostro and A. Piersanti, M. Cocco (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143, Rome, Italy)

We study the stress field produced by a shear dislocation in a spherical, viscoelastic, stratified, self-gravitating earth. This model allows for a self-consistent investigation of coseismic and postseismic stress fields over distances of thousands of kilometers, where plane geometry fails. We apply this method to compute the static coseismic and postseismic stress changes caused by a shear dislocation in the near source region. We compare the displacement field simulated with this procedure with those resulting from an elastic flat-earth dislocation model. Our results emphasize that viscoelastic relaxation should be taken into account to study the stress transfer and the fault interaction over time scales ranging between few years to several centuries. We study the sequence of historical earthquakes that occurred during the last four centuries along the southern Apennines seismogenic belt (Italy).

INTERNAL STRESS FIELD AT MT. VESUVIUS AS DUE TO GRAVITATIVE AND STRUCTURA L EFFECTS: IMPLICATIONS FOR THE LOCAL SEISMICITY.

S. Petrazzuoli, C. Troise,F. Pingue, P. Capuano and **G. De Natale** (Osservatorio Vesuviano,via A. Manzoni,249, 80123 Napoli, Italy)

The internal stress field at Somma-Vesuvius has been modeled as due to the gravi tative effect of the volcanic edifice, and conditioned by the main structural he terogeneities. In particular, a higher rigidity body, with center at the crater axis and radius of about one kilometer has been simulated. Such rigidity anomaly has been recen tly inferred by tomography studies with active and passive sources. The effect o f this structural anomaly is to concentrate shear stress along its boundaries. A finite element scheme for axisymmetric media has been used for the modeling. The results point out the importance of the gravitative effect of the volcanic edifice and of the central high rigidity body. Such effects are able to explain the background seismicity at Somma-Vesuvius occ urring in quiescent periods, without postulate any tectonic or magmatic external influence. Local earthquakes occur at Somma-Vesuvius at an average rate of some hundred events per year. They all appear concentrated within the high rigidity body, in agreem ent with theoretical stress modeling. Moreover, the observed variability of infe rred focal mechanisms can be explained, in terms of such a model, as related to the curvature o f the boundaries of the rigid body anomaly.

A COMPREHENSIVE STUDY OF THE EFFECT OF NON-UNIFORM STATION DISTRIBUTION ON THE INVERSION FOR SEISMIC MOMENT RELEASE HISTORY AND DISTRIBUTION FOR A HASKELL-TYPE RUPTURE MODEL

A. Sarao' (Dipartimento di Scienze della Terra, Universita' di Trieste, I-34127 Trieste, Italy), S. Das (Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK), and P. Suhadolc (Dipartimento di Scienze della Terra, Universita' di Trieste, I-34127 Trieste, Italy)

In order to determine the effect of non-uniform azimuthal distribution of seismic stations around an earthquake on the determination of the details of the earthquake faulting process, we use artificial accelerograms at regional distances and solve the inverse problem. Different station configurations are used, one being a very uniform distribution and the rest very non-uniform. In most cases, we use much larger spatial and temporal cell sizes in the inversion than we use to construct the artificial data. We use the method of linear programming and stabilize the solution by the use of physical constraints. We find that using a cell size almost double the wavelength of interest, we are able to reproduce the solution of the problem, even when we add a small amount of random noise to the artificial data, provided the medium structure is known. For a shallow thrust fault, we show that the best station configuration is when the stations are on the hanging wall, and even six stations are enough to reproduce the moment release history and distribution. We also analyzed the effect of the rupture propagation direction on the results of the inversion showing that even four stations are enough to retrieve the rupturing process if they are placed in the forward direction of the rupture propagation. When an optimal azimuthal station coverage is not available, our results show that the solutions can be improved by using well-established physical constraints. Finally, we find that proper knowledge of source medium structure is essential to recover the source process details.

NUCLEATION PHASES AND FIR FILTER EFFECTS

F. Scherbaum (Institut fur Allgemeine und Angewandte Geophysik, Ludwig-Maximilians-Universitaet Muenchen, Theresienstr. 41, D 80333 Muenchen)
M.-P. Bouin (Department of Earth Sciences, Parks Road, Oxford. OX1 3 PR, U.K.)

Growing evidence suggests that the main P phase of earthquakes is often preceded by an interval of low amplitudes. These phases have been commonly interpreted as reflecting the early stage of the rupture process. A striking property of these phases is that their durations scale with the cube root of the seismic moment of the main event. While these results have been obtained based on instruments with a causal response, due to the lack of phase distortions most modern seismic recordings systems use acausal linear phase FIR filters. Because of their symmetric impulse response these filters can also generate precursory signals to impulsive seismic arrivals. Using the method developed by Scherbaum (1996) to remove FIR filter related acausal effects, we have analysed numerous precursory signals from different instruments. We found that contrary to common belief, FIR filter artifacts can become impossible to be identified visually. If data from different instruments and/or sampling rates are combined, the situation becomes especially dangerous for nucleation phases studies. Those FIR filter artifacts which are hard to recognise can exhibit surprisingly similar scaling properties to the cube root moment scaling suggested for nucleation phases. We propose a simple model for this scaling relationship and discuss strategies for the analysis of nucleation phases from seismic records which have been filtered by linear phase FIR filters.

SPATIAL HETEROGENEITY OF RUPTURE PROCESS IN RELATION TO FAULT GEOMETRY

H. Sekiguchi, K. Irikura and T. Iwata (Disaster Prevention Research Institute, Kyoto University Gokasho, Uji, Kyoto, 611, Japan)

We examined the correlation between spatial characteristics of rupture process (i.e. rupture time, shape and duration of the moment rate functions) and the geometry of the estimated faulting involved in the 1995 Hyogo-ken Nanbu, Japan, earthquake. We attempted to study detailed processes near the rupture initiation and termination area. For this purpose we performed the waveform inversion using near source records. The previous waveform inversion studies of this earthquake used few near source records, be cause most of them were obtained at stations on the Osaka sedimentary basin and not far from the basin edge. We examined the applicability of the flat-layer approximation to the 3D realistic crustal structures in calculating Green's functions for such stations. Many source inversion studies using local strong motion, geodetic, and teleseismic data have shown that the causative faults ran along the prescribed active faults. Deducing from our results and all the other source inversion studies on this earthquake, the causative faults consisted of three main subfaults, deep beneath the Akashi strait, shallow beneath the north part of the Awaji Island, and deep beneath the Kobe downtown. The rupture started at a bend or a step of the prescribed active faults at the Akashi strait, propagated bilaterally to NE direction on the first subfault and to SW on the second subfault. The rupture to NE was impeded at a fault bend or a step, propagated again on the third subfault, and stopped near a branching of the prescribed faults.

ELECTRICAL RESISTIVITY AND RUPTURE PROCESSES

S. Tomecka-Suchoń and H. Marcak
(AGH, Institute of Geophysics, Al. Mickiewicza 30, PL-30059 Kraków, Poland)

During the last years it has become more and more obvious that the variations of electrical conductivity measured in straining rock reflect essentially changes of the parameters describing the statistical distribution of crack lengths. Thus, laboratory studies of the electrical resistivity of rock samples under loading may give clues concerning the onset of rupture. This work reports on such experimental studies, mainly with coal samples, and deals with some theoretical research trying to link the experimental results to particular physical processes. It describes the development of a crack system and presents a mathematical model for investigating the electrical resistivity of coal and other rocks in which electric current is conducted mainly by electrolytes. The measurements were carried out under a stable confining pressure of 20 MPa and differential stresses up to 60 MPa. The results are therefore directly relevant to rupture processes occurring at very shallow depths, particularly in mines. The investigations were actually undertaken with mining activities in mind, but the results can be extrapolated and provide information related to shallow-focus seismic events.

ON THE MECHANISM OF UNREST EPISODES AT CAMPI FLEGREI (ITALY) CALDERA: THE JOINT ROLE OF MAGMA CHAMBER AND SHALLOW AQUIFERS.

C. Troise, G. De Natale, C. Godano, F. Di Sena, U. Coppa and P. Capuano
(Osservatorio Vesuviano,via A. Manzoni,249, 80123 Napoli, Italy)

The local seismicity at Somma Vesuvius during the last twentyfive years consists of some hundreds events per years. The mechanisms of generation of such seismicity, in quiescent periods, are not well known. The accurate study of earthquake focal mechanisms should be a powerful tool to answer this question. This work reports some preliminary results obtained by the computation of focal mechanisms of microearthquakes at Somma Vesuvius (ML¡3.2). Such computation has been carried out by the use of a Bayesian procedure based on the joint inversion of P wave polarities, S wave polarisations and S/P amplitude ratios. Most of the mech anisms have been computed by using just P wave polarities and S wave polarisations, whi ch are the most robust kinds of data. Some tests have been performed on the additional use of S/P amplitude ratios. The earthquake data set comes from two episodes of intense seismicity occurred on 1989 and on 1995. In the first period, the surveillance n etwork of Osservatorio Vesuviano consisted of few analog stations. For this reason, 5 addi tional digital three componet stations were added. In this case, we have few P wave pol arities, but the inclusion of a small set of S wave polarisation data coming from digital stations provides a set of well constrained focal mechanisms. Results show that focal mechanisms for the two periods of intense seismicity are not substantially different. Focal mechanisms generally indicate strike slip faultin g. In both cases, however, we observe a large variability in the P and T axes.

SE3 Signals of ice-sheet and glacier instability on sea level, gravity field and Earth's rotation

Convener: Lambeck, K.
Co-Conveners: Vermeersen, L.L.A.; Wolf, D.

HIGH VISCOSITY CONTINENTAL ROOTS AND POST GLACIAL DEFORMATION FIELD: A SEMI-ANALYTIC APPROACH

G. D'Agostino (Dipartimento di Fisica - Settore di Geofisica, Universita' di Bologna, Viale Berti Pichat 8, 40127 Bologna, Italy)
R. Sabadini (Dipartimento di Scienze della Terra - Sez. Geofisica, Universita' di Milano, Viale Cicognara 7, 20129 Milano, Italy)
G. Spada (Dipartimento di Fisica - Settore di Geofisica, Universita' di Bologna, Viale Berti Pichat 8, 40127 Bologna, Italy)

The presence of high viscosity continental roots under deglaciated areas affects the calculation of the post-glacial surface deformation field on a viscoelastic Earth's models. To derive the harmonic components of surface displacement field produced by the ice load we take advantage of a semi-analytic method based on the normal mode theory. We show that the amplitude of the horizontal displacement is substantially reduced in proximity to the edge of the ice cap, because the increase of viscosity under the load inhibits the flow of the upper mantle: the topography is on the opposite essentially unaffected. The effects of lateral heterogeneities in the upper mantle are presented for different mantle models, varying the size of the continental root and the viscosity contrast between lower and upper mantle.

Secular Redistribution of the External and Internal Masses of the Earth and Their Role in the Variations of the Geopotential and Earth's Rotation

Yu.V.Barkin (Astronomical Institute, MSU, Univ. pr-t, 13, 119899, Moscow)

New method of the investigation of the perturbed rotation of the deformable celestial bodies with elastic mantle and changable in the time cover has been developed. Secular and periodic effects in rotation are found by method of the perturbation theory and are approximated by solution of the rotation equations of the isolated body in Andoyer's and Euler's variables. As unperturbed rotation the Chandler's-Euler's rotational motion of the axisymmetric body is used (Barkin, 1994). The compact expressions for secular variations the components of the angular velosity were presented in terms of the secular variations of the components of the inertia tensor and relative angular moument of the external cover. The solution was obtained for arbitrary unperturbed values of the angle between the angular moument of the body and its polar inertia axes. In particular this solution can be used for analysis of the Earth's rotation. On the basis of the simple models of the level sea and ice sheets of Greenland and Antarctic changes (Nakiboqlu, Pointon, 1987), the secular variations of the geopotential coefficients first and second harmonics were calculated. Also secular variations of the durnal rotation and components of the pole drift, slow geocenter displacement and secular drift of the rigid core due to abovementioned processes were studied. The role of the other processes (post-glacial rebound, plate motion, subduction and accumulation of the oceanic plate masses, global rotation of the lithosphere, possible changes of the surface of the outer core and motions of the RC) for considered geodynamical phenomena are studied complexly.

DETECTION OF HYPOTHETICAL GLOBAL WARMING EFFECTS

S. R. Dickman (Geology Department, State University of New York, Binghamton, NY 13902-6000 USA)

The addition of meltwater to the oceans may generate significant dynamic changes in sea level on time scales of days to months. This talk describes a theoretical experiment whose goal was to determine if such short-term signatures in sea level -- or the associated changes in gravity and Earth rotation -- can be used to detect the type of episodic ice-sheet melting hypothetically expected from global warming. In this experiment melting was confined to Antarctica. As a preliminary step, the oceans were forced by the changes in gravity produced from the hypothetical melting scenario, but not by the addition of meltwater itself. The changes in sea level were calculated using my spherical harmonic ocean tide model. The melting history was characterized by time scales of months to years (periods for which the tide model yields reasonable predictions). The results demonstrate that the dynamical sea-level signals produced by the gravity forcing are preferentially enhanced compared to the 'eustatic' trend contained in the forcing. Such enhancements could be even more significant once mass forcing is included. Short-term, dynamical signals may thus prove useful in detecting actual icecap melting.

DEFINING THE EUSTATIC SEA-LEVEL CURVE SINCE THE LAST GLACIAL MAXIMUM

Kevin Fleming, **Paul Johnston**, Dan Zwartz and Yusuke Yokoyama (RSES, Australian National University, Canberra ACT 0200, Australia)

A eustatic sea-level curve has been derived from far and intermediate-field sites for the period following the Last Glacial Maximum (LGM) to the present day. In order to produce a curve which may be considered *global*, several corrections need to be made to accommodate spatial variation in relative sea-level change due to glacio-hydro-isostasy and changes in the Earth's pole of rotation, which result from the redistribution of ice and water. Far-field sites are the most useful in this exercise owing to their relative insensitivity to details of former ice sheet geometry and earth rheology. The sites of particular importance to this work were Barbados (an intermediate to far-field site), the Huon Peninsula of Papua New Guinea and Tahiti (both far-field sites). Corrections were also applied to these sites to account for non-isostatic vertical movement.
Several features of this curve have become apparent: 1) there is strong evidence for an increasing ocean volume during the Late Holocene such that the eustatic sea-level around 6 ka BP was *ca* 3-4 metres lower than today, 2) there has been significant variation in the rate of eustatic sea-level rise since the LGM. Although the dominant episodes may be resolved, the uncertainties arising from, for example, the relationship between sea-level and the dated samples means that more subtle features may not be positively identified.

JOINT INVERSION OF THE RATES OF POLAR MOTION AND GEOID CHANGE FOR DEEP MANTLE VISCOSITY AND CURRENT GLACIAL MELTING

P. Johnston, K. Lambeck and G. Kaufmann (RSES, Australian National University, Canberra ACT 0200, Australia)

The inertia tensor of the Earth continues to change today in response to the change in surface load caused by the Late Pleistocene deglaciation. Polar motion is caused by changes in the off-diagonal terms of the inertia tensor which are proportional to the degree 2 (order 1) spherical harmonic component of the ice load and Earth response. The dependence of polar motion on load size, location, geometry, history and Earth rheology is examined.
The acceleration of the node of near-Earth satellite orbits is proportional to a lumped sum of the rate of change of the even zonal spherical harmonic components of the geoid but is dominated by the degree 2 component ($\dot{C}_{20}$). Therefore the dependence on Earth rheology for both $\dot{C}_{20}$ and polar motion predictions should be similar. However, predictions of polar motion are much less sensitive to changes in the surface load at high latitudes than those for $\dot{C}_{20}$.
Polar motion observations can be employed to infer an average deep mantle viscosity which is largely free from error due to uncertainties in the recent and present deglaciation histories of the high latitude ice sheets in Greenland and Antarctica. On the other hand, predictions of $\dot{C}_{20}$ are sensitive to both the deep mantle viscosity and recent changes in the glacial load. Using the viscosity profile derived from polar motion, observations of the acceleration of the node of near-Earth satellites constrain the rate of current and recent melting.

MODELLING OF GLACIAL STRESSES: IMPLICATIONS OF THE FINITE VISCOSITY OF THE LITHOSPHERE

Volker Klemann (Institut für Planetologie, Universität Münster, Wilhelm-Klemm-Str. 10, D-48149 Münster, Germany)
Detlef Wolf (GeoForschungsZentrum Potsdam, Telegraphenberg A17, D-14473 Potsdam, Germany)

The enhanced seismicity observed in parts of Fennoscandia is usually explained by *tectonic* stresses. The question of the contribution of *glacial* stresses to the seismicity has not been finally settled yet.

In order to understand the glacially induced stress field it is necessary to consider the complete sequence of *glacials* and *interglacials* during the Pleistocene. The characteristic time scales of this sequence are the period of ice accumulation ($\sim 10^5$ a), the period of ice disintegration ($\sim 10^4$ a) and the Pleistocene period ($\sim 10^6$ a). Whereas the lithosphere responds elastically for the short-period parts of the glacial spectrum in good approximation, the long-period part may require that the *finite viscosity* of the lithosphere be accounted for.

The objective of the present study is to examine effects due to viscous relaxation in the lithosphere on the glacial stress field more closely. The calculations presented are based on an *axisymmetric* load model and a stratified *Maxwell-viscoelastic* earth model. The viscosity of the lithosphere is parameterized according to the stratification expected for temperature activated diffusion creep. We show that the neglect of the finite viscosity of the lithosphere is usually not justified for the calculation of glacially induced stresses.

THE SENSITIVITY OF GIA OBSERVABLES TO A LOW VISCOSITY LAYER AT THE BASE OF THE UPPER MANTLE: IMPLICATIONS FOR CONSTRAINING GLOBAL MELTING EVENTS FROM $\dot{J}_l$ DATA

G. A. Milne[1], J. X. Mitrovica[1] and A. M. Forte[2]. (1. Department of Physics, University of Toronto, 60 St. George St., Toronto, Canada, M5S 1A7; 2. Institute de Physique du Globe de Paris, Dépt. de Sismologie, 4 Place Jussieu, Paris 6, 75252 France.)

A number of recent studies have argued for a thin low viscosity layer at the bottom of the upper mantle on the basis of modelling low degree non-hydrostatic geoid data. We present predictions of a large suite of glacial isostatic adjustment (GIA) observables to consider whether the GIA data are sensitive to this postulated fine scale viscosity feature. Our results show that while predictions of most GIA observables are relatively insensitive to such structure, predictions of $\dot{J}_l$ show surprising sensitivity ($\sim$ 40% of the predicted signal for degree 2). The $\dot{J}_2$ perturbation associated with the low-viscosity layer is twice the signal expected from ongoing melting of small ice sheets and glaciers and roughly the same amplitude as the signal arising from a present-day mass flux in the large polar ice caps equivalent to $\sim$ 0.5mm/yr eustatic sea level change. Since the observed $\dot{J}_l$ are affected by a number of poorly constrained signals independent of GIA, the predicted sensitivity of these observables to the postulated low viscosity layer cannot (at present) be used to test for the existence of this feature. This sensitivity also reduces our capability to set useful constraints on Earth rheology and/or ongoing global melting events using the observed $\dot{J}_l$ signals.

JOINT INVERSIONS FOR MANTLE VISCOSITY: RESULTS & IMPLICATIONS

J. X. Mitrovica (Department of Physics, University of Toronto, Canada, M5S 1A7, 416-978-4946, jxm@physics.utoronto.ca)
A. M. Forte (Institute de Physique du Globe de Paris, Dépt. de Sismologie, 4 Place Jussieu, Paris 6, 75252 France)

Glacial isostatic adjustment (GIA) is manifest in a wide range of geophysical observables. Predictions of these observables are complicated by the sensitivity of the adjustment to both the space-time history of the late Pleistocene ice mass variations and the rheology of the planet. We report on our ongoing efforts to constrain the radial profile of mantle viscosity using non-linear inverse procedures applied simultaneously to data associated with mantle convection and GIA. Our data includes a globally distributed set of post-glacial relative sea level (RSL) curves and long-wavelength (up to spherical harmonic degree 8) free-air gravity anomalies. We find that both these data sets may be reconciled using a single profile of viscosity characterized by a significant increase ($\sim 1-2$ orders of magnitude), with depth, in the mantle. By considering various subsets of the GIA RSL data set we also investigate the extent to which lateral heterogeneities in rheology need to be invoked to reconcile the observables. Finally, using the results of the inversions, we estimate a suite of present-day signatures associated with the rebound process (e.g., J_ℓ harmonics, length-of-day variations, polar wander, 3-D crustal deformations). We explore the consistency between our predictions and recent geodetic observations, and also use these a-posteriori calculations to place bounds on the extent of late Holocene melting of polar ice as well as on ongoing melting events.

PROGLACIAL FOREBULGE COLLAPSE AND MANTLE VISCOELASTICITY

W.R. Peltier (Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7)

Outboard of the continental ice sheets that existed on Earth's surface at last glacial maximum (LGM-approximately 21,000 years before present), the local radius of the planet was increased by the outflow of material from under the ice sheets that was required to accommodate the viscous sub-glacial depressions. As a consequence of deglaciation, these forebulge regions collapse, thus leading to a continuing rise of relative sea level in such locations. There are two such geographical regions on the Earth's surface that are especially well sampled by high quality ^{14}C dated relative sea level observations. These are, firstly, the east coast of the continental United States which straddles the still collapsing forebulge of the Laurentide ice sheet that was centred on Hudson Bay in Arctic Canada. Secondly, there is the region that was outboard of the Fennoscandian ice complex, a region that includes the British Isles which is especially rich in high quality observations of postglacial relative sea level change. Data from both regions provide an extremely useful means of testing the predictive capacity of the radial viscosity profiles that have recently been obtained on the basis formal inversion of a wide range of observations related to the global glacial isostatic adjustment phenomenon (e.g., see W.R. Peltier, Science, 273, 1359-1364, 1996). The data from these regions of forebulge collapse strongly confirm the essential validity of these formally derived models.

MANTLE LAYERING AND LONG-TERM ROTATIONAL RESPONSE OF THE EARTH TO GLACIAL CYCLES

R. Sabadini (Dipartimento di Scienze della Terra, Università di Milano, Sezione Geofisica, Via L. Cicognara 7, I-20129 Milano, Italy)
L.L.A. Vermeersen (Geodetic Institute, Stuttgart University, Keplerstrasse 11, D-70174 Stuttgart, Germany)

Rheological and constitutional stratification of viscoelastic Earth models based on PREM (Dziewonski & Anderson 1981) plays a crucial role in the long-term rotational response of the planet to the isostatic readjustment to surface (ice-sheets) and internal (convection) loads. The characteristic time scale for the readjustment of the rotational bulge appears to be a function of the number of viscoelastic layers, reaching saturated continuum limits at about 30 layers. Thus both the present-day true polar wander due to Pleistocene deglaciation and the amount of polar wander accumulated during the ice-ages, are sensitive to the PREM stratification. When our theory is applied to the inference of the viscosity profile of the Earth's mantle, as required by the simultaneous fit of the latest true polar wander data and changes in the degree two component of the geopotential ($\dot{J}_2$), we obtain that the upper mantle viscosity is about $1 - 5 \times 10^{20}$ Pa · s, while the viscosity of the lower mantle is about a factor 25 higher, in agreement with some recent relative sea level analyses. When the rotational response of the planet to the continuous occurrence of ice ages is considered, our findings may impact the interpretation of the effects of ice loading on climate variability induced by changes of insolation of the planet due to true polar wander.

INFERENCES ON MANTLE RHEOLOGY FROM TEMPORAL CHANGES IN THE ZONAL HARMONICS OF THE GEOID

L.L.A. Vermeersen (Geodetic Institute, Stuttgart University, Keplerstrasse 11, D-70174 Stuttgart, Germany)
R. Sabadini (Dipartimento di Scienze della Terra, Università di Milano, Sezione Geofisica, Via L. Cicognara 7, I-20129 Milano, Italy)
S. Borgo (Dipartimento di Fisica - Settore Geofisica, Università di Bologna, Viale Berti Pichat 8, I-40127 Bologna, Italy)

Satellite-derived measurement data of the non-tidal part of the temporal changes in the low-degree zonal harmonics of the geoid dJ_n/dt, with n up to degree 6, are getting progressively more accurate. This implies that these values are becoming to be reliable enough to be used as constraints in geophysical models, where they eventually can discriminate between models on the forcing mechanisms (e.g. Pleistocene deglacation, contemporary ice-water redistributions) and can lead to information on the rheological properties of the Earth (e.g. mantle viscosity, lithosphere thickness).
We present simulations based on a realistically stratified Earth model (PREM of Dziewonski & Anderson 1981) and realistic ice models (ICE-3G of Tushingham & Peltier 1992 for the deglaciation phase of the Wurm-Wisconsin ice age) which use the dJ_n/dt data as constraints. Our viscoelastic models are virtually completely analytical, allowing for high modeling accuracies. We show the effects of the number of layers of the Earth model in forward simulations, and discuss the consequences this has for the uniqueness of mantle viscosity solutions in inversions.

MANTLE VISCOSITY INFERRED FROM FENNOSCANDIAN STRANDLINE DATA

K. Wieczerkowski (Institute of Planetology, University of Münster, Wilhelm-Klemm-Str. 10, D-48149 Münster, Germany)
J.X. Mitrovica (Department of Physics, University of Toronto, 60 St. George Street, Toronto, Ontario M5S 1A7, Canada)
D. Wolf (GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany)

The *postglacial rebound* of the Fennoscandian Shield has raised Holocene strandlines up to 200 m above present sea level. The space-time distribution of these strandlines was used previously (e. g. McConnell 1968, *JGR*, **73**, 7089) to calculate the *relaxation spectrum* of rebound, i. e. the decay time of the uplift versus the wavelength of the deformation. Since the relaxation spectrum is unbiased by assumptions regarding the space-time history of the load, it has played a significant role in the inference of *mantle viscosity*.

Previous relaxation spectra were derived on the basis of highly contentious hypotheses on strandline evolution (Wolf 1996, *GJI*, **127**, in press). In this study we use strandlines based on more reasonable assumptions. Accounting also for the results of synthetic strandline calculations, we derive a new relaxation spectrum.

Following Mitrovica & Peltier (1993, *GJI*, **114**, 45), we apply formal *inverse theory* to the new relaxation spectrum. In particular, we present estimates of the resolving power of the data as well as revised constraints, including uncertainties, on mantle viscosity.

BIFROST: MONITORING AND GEOPHYSICAL ANALYSIS OF FENNOSCANDIAN CRUSTAL DEFORMATIONS

H.-G. Scherneck and J.M. Johansson (Onsala Space Observatory, S-439 92 Onsala, Sweden)
J.X. Mitrovica (Dept. of Physics, Univ. Toronto, Ontario, Canada)
J.L. Davis (Harvard-Smithonian Center for Astrophysics, Cambridge, MA)

Within the BIFROST project (Baseline Inferences for Fennoscandian Rebound Observations, Sea level, and Tectonics) we analyze deformation of the crust in Fennoscandia (see *EOS*, 77, No. 35, p 337). Continuous observations using the Global Positioning System (GPS) have been carried out starting in August 1993 at a permanent network of GPS stations, consisting of 21 sites in Sweden (the SWEPOS array) and additional European IGS stations. Crustal deformations in this area are due primarily to visco-elastic isostatic adjustment after the deglaciation at the end of the Pleistocene. Space geodetic measurements permit inference of 3-D velocity vectors at each field point; tide gauge data from the same region provide independent constraints on the adjustment process.
We present motion estimates for the BIFROST network and compare these with glacial isostatic adjustment models. The latter include a suite of global ice histories and mantle viscosity profiles; they incorporate a self-consistent ocean-load response. We find that the gross features of the predictions are consistent with the GPS and tide gauge derived motion. One-sigma uncertainties for the vertical rates are below 1 mm/yr, (0.3 mm/yr horizontal). In a few cases, which we discuss, our data show anomalies which fall outside the range suggested by the modelling.

MANTLE VISCOSITY DERIVED FROM CHANGES IN ROTATION INDUCED BY PLEISTOCENE ICE CYCLES

L.L.A. Vermeersen (Geodetic Institute, Stuttgart University, Keplerstrasse 11, D-70174 Stuttgart, Germany)
A. Fournier (Departement des Sciences de la Matiere, ENS Lyon, 46 Allee d'Italie, F-69364 Lyon Cedex 7, France)
R. Sabadini (Dipartimento di Scienze della Terra, Università di Milano, Sezione Geofisica, Via L. Cicognara 7, I-20129 Milano, Italy)

Present-day true polar wander and changes in the second degree harmonic of the geoid J_2 are studied for a realistically stratified Earth model (PREM of Dziewonski & Anderson 1981) and a realistic Pleistocene ice sheet model (ICE-3G of Tushingham & Peltier 1992). The novelty of our approach stands on the application of a virtually fully analytical normal mode theory to self-gravitating Maxwell Earth models containing a large amount of layers.
Our results indicate that models containing about 30 layers have reached continuum limits. If it is assumed that only the waxing and waning of Pleistocene ice sheets affects present-day true polar wander and changes in J_2, we find from combining our modeling results with the observed present-day true polar wander and dJ_2/dt that the upper mantle viscosity is about $1 - 5 \times 10^{20}$ Pa · s, while the lower mantle viscosity is a factor 25 higher. These values for the mean viscosity of the upper and lower mantle are in close agreement with those found from some recent relative sea-level analyses and convectively supported long-wavelength geoid anomalies.

SE4 Active and past subduction in the Mediterranean: observations and modelling

Convener: Amato, A.
Co-Conveners: Jolivet, L.; Richardson, R.M.; Wortel, M.J.R.

Sponsorship: EUG

DYNAMIC MODELLING OF SUBDUCTION IN THE NORTHERN APENNINES

S. Barba (Istituto Nazionale Geofisica, Via Vigna Murata 605, 00143 Roma, Italy)
A. Negredo, E. Carminati and R. Sabadini (UniversitÓ degli Studi di Milano, dip. Scienze della Terra - sez. Geofisica, Via Cicognara 7, 20100 Milano, Italy)

Starting from geophysical data, we developed a 2-D geodynamic model to reproduce the present-day movements and stress distribution along a section crossing Thyrrenian Sea, Northern Apennines and Adriatic Foredeep. The finite elements model assumes a linear viscoelastic rheology. In this area, subcrustal seismicity down to 90 km and a high velocity zone down to 200 km depth are evidence of an ongoing subduction of the continental Adriatic lithosphere. The density anomalies due to phase transformation within the subducting plate cause gravitational sinking and roll-back of the slab. When we consider a subducted slab 200 km deep, the negative slab buoyancy exhibits a strong subsidence of the Adriatic foredeep and Tuscany. The high values of heat flow and the extensional tectonics in Tuscany and Northern Thyrrenian sea made us account for a negative density contrast in the lithosphere, related to a lithospheric thinning associated with a process of active rifting. This process reduces the subsidence in Tuscany and Adriatic foredeep. We considered also the effects of a slab detachment to obtain uplift in Tuscany and, as a flexural response, subsidence in the Adriatic foredeep. We conclude that the slab pull dominates the problem and that another mechanism should be taken in account to reproduce geological data.

TOMOGRAPHIC IMAGES OF THE NORTHERN APENNINES UPPER MANTLE HIGH-VELOCITY ANOMALY

M.G. Ciaccio and G.B. Cimini (Istituto Nazionale di Geofisica, Rome, Italy)

We present refined tomographic images of the deep structure beneath northern Apennines obtained by inverting teleseismic relative arrival-time data, collected from the Italian Network during the last five years and from a temporary linear array of 10 seismic stations deployed during the summer of 1994. This transect, the northernmost of the three transects carried out in the frame of EC project GeoModAp (contract EV5V-CT94-0464), crossed peninsular Italy from Corsica to Mt. Conero on the Adriatic coast. Instruments on the profile, consisting of continuous digital recorders and 5-seconds or broad-band sensors, were deployed with an average spacing of about 35 km. The data used in the imaging are the travel time residuals of P, pP, sP, PcP, and PKPdf phases, computed with respect to the improved global travel-time model *ak135* (Kennett *et al.*, 1995), and inverted with a modified version of the ACH technique (Evans and Achauer, 1993). The new tomographic images confirm the existence of a high-velocity anomaly located in the internal part of the northern Apenninic arc. This feature is interpreted to be the seismic expression of a remnant lithospheric slab that is presently sinking beneath the belt. A lower crust high-velocity anomaly is also reconstructed by the 3D inversion but is not as well constrained due to the still inadequate station spacing in the region.

MODELLING OF THE VELOCITY AND STRESS FIELDS IN THE AEGEAN REGION

S. Cianetti and M. Boccaletti (Dipartimento di Scienze della Terra, Università di Firenze, Italy)
P. Gasperini (Dipartimento di Fisica, Settore di Geofisica, Università di Bologna, Italy)
C. Giunchi (Dipartimento di Scienze della Terra, Università di Milano, Italy)

Recent satellite geodetic measurements definitely cleared the pattern of the velocity field in the Aegean-Anatolian area. This can be described by the anticlockwise rotation of this block relative to Eurasia, around a pole located in the Eastern Mediterranean some hundreds of chilometers north of the Egyptian shoreline. On the other hand, the time evolution of the stress field has been inferred from studies on the fault kinematics. In this work, we compare these observables with the results of finite element modeling of the tectonic evolution of the Aegean and surrounding areas in order to better understand the physical mechanisms which generated the observed velocity and stress patterns. We found that the present observed fields can be well reproduced imposing simple boundary conditions including: the northward displacement of the Arabian plate; the locking of eastward motion in northwestern Greece and the suction force at the Hellenic trench. The observed variation in the stress field occurred at 0.9 Ma b.p. can also be modeled assuming a change in the velocity of the Arabian indenter.

GEOPHYSICAL RESEARCHES IN THE IONIAN SEA

G.A.Dehghani, J. Hartmann, H.B. Hirschleber (Institut für Geophysik, Universität Hamburg, Bundesstrasse 55, D-20146 Hamburg, Germany)
W. Hieke (TU München, Lehrstuhl für Geologie, Lichtenbergstr. 4, D-85747 Garching, Germany)

Intensive geophysical researches were carried out in the Ionian Sea during the cruises VALDIVIA 120 (1992) and METEOR 25/4 (1993). The main objectives of these German funded projects were to understand the geological structure of the Ionian Abyssal Plain and also to study the Mediterranean Ridge accretionary complex. The geophysical data were collected along several profiles of three different transects. The comparison of the seismic reflection interpretation with the gravity and magnetic data reveals some interesting results. The data suggest, that the evaporites were deposited in basins separated by elongated structures. The base of the evaporites could be mapped and traced over a long distance into the Mediterranean Ridge. Prominent tectonic units and structures in the abyssal plain like Victor-Hensen and Nathalie can be traced very clear. According to 2-D models Victor-Hensen and Nathalie structures have the same subbottom feature.

SEISMIC IMAGES FROM THE CONVERGENCE ZONE OF THE EASTERN MEDITERRANEAN: PRELIMINARY RESULTS FROM REPROCESSING STRAKHOV CRUISE 5.

Docherty, C., Vidal, N., Kläschen, D. and von Huene, R. (GEOMAR, Wischhofstrasse 1-3, Kiel, D24148 Germany)

We present the preliminary results of the re-processing of 1700 km of deep seismic data recorded in the eastern Mediterranean. The profiles extend from the south of Cyprus to the Syrian coast, most trending approximately NNW-SSE and are connected by a long perpendicular tie profile. This geometry crosses perpendicular to the diverse structural elements in the area and exposes lateral changes along arcuate ridges that run between Cyprus and the Levantine coast. These ridges are in part south-verging thrusts, testimony to the convergence between the African and Turkish plates. Attenuation of strong multiple energy reveals the stratigraphy of the thick Tertiary-Mesozoic sequence of the Phoneacean basin, and unveils a prominent band of reflectors between 8-9 s TWT, which is interpreted as the reflective upper crust. Pre-stack depth migration provides the first images in depth of the basin, as well as details of the prominent Erastosthenes seamount, colliding with the southern margin of Cyprus.

INITIATION AND EVOLUTION OF THE SUBDUCTION PROCESS IN THE CENTRAL MEDITERRANEAN: INSIGHT FROM GEOLOGICAL DATA AND LABORATORY EXPERIMENTS

Claudio Faccenna, Massimo Mattei, Alessio Argentieri, Renato Funiciello (Dip. Sc. Geol., Univ. Roma Tre, Roma, Italy)
Laurent Jolivet (Dep. Sc. Terre, Univ. Cergy Pontoise, Cergy-Pontoise, France)
Philippe Davy (Geosciences Rennes, Rennes, France)

Geophysical investigations pointed out the presence of a subducting slab below the Calabrian arc and possibly below the Northern Apennines. A general agreement exists in consider those small slabs as the remnant of a larger west dipping subduction process. We collected geological and paleomagnetic data and we performed kinematic reconstruction of the extensional process occurred at the back of the western subduction processes in the Mediterranean region. We performed 2D and 3D laboratory experiments at the Laboratory of Rennes (France) and Rome (Italy), to describe the mechanism of initiation and evolution of subduction processes, with emphasis to subduction initiation, back-arc extension and slab break-off processes. The results of experiments are compared with geological and tectonic evolution of the Central Mediterranean region.

A CRUSTAL SECTION ALONG THE NORTHERN APENNINES (ITALY) FROM CROP-03 WIDE-ANGLE-REFLECTION SEISMIC EXPERIMENT.

R. de Franco, G. Biella, G. Caielli, A. Corsi, G. Boniolo, M. Maistrello, A. Morrone (Istituto di Ricerca sul Rischio Sismico CNR, v. Bassini,15 20133 Milan, Italy) F. Ponziani (Osservatorio Sismico "A. Bina",v. Borgo XX-VI,74, 06121 Perugia, Italy). G. Pialli (Dip. Scienze della Terra. P.ce Universita', 06100, Perugia, Italy).

Integrative Wide Angle Reflection seismic data, in the frame of CROP-03 (Italian near vertical deep reflection project), along a Northern Apennines (Italy) transect were acquired. The processing and the data interpretation are presented. Three main crustal domains were recognized: 1) The Perityrrhenian-Tuscan domain has a crustal thickness of 2212 km with a high reflective lower crust 5-9 km thick and an upper mantle velocity of 7.81.2 km/s. High attenuation, caused by the anomalous thermal field in the area, at all crustal and upper mantle depths are observed. Shear zones east down-dipping were detected indicating distensive crustal structures. 2) The transitional domain is characterized by a spreading in the lower crust reflectivity and discontinous PmP Moho reflections. A mantle wedge of the Tuscan mantle east up-dipping is observed doublening the Adriatic crust for about 30 km. 3) The Adriatic domain shows a thickness of the lower crust ranging from 10 km to 15 km showing a high and structured reflectivity with a Moho depth of 3213 km and an upper mantle velocity of 8.01.2 km/s. A deep subducted structure, in the depth range of 35-50 km, is observed below the Trasimeno lake and Tiber valley. Crustal shear zones west down-dipping indicating the compressive limits of the Apenninic chain are detected.

EAST EUROPEAN PLATE SOUTH-WEST BORDER

Gheorghe GARDU ("Prospectiuni" S.A.,Bucuresti, Str.Caransebes, Nr.1, sector1, Romania)

East-European Plate and Moesian Plate probably formed a single continent, wich broke up during the late Precambrian time. Evidences in suport of this hypothesis are the green schist rocks with basic character, wich outcrops in central Dobrogea, and are catch up in conglomerates of the flisch suite of the East Romanian Carpathians, and also are found in continuity on the northern border of the Black Sea, in Crimeea. To note the medusoidal forms of life found in green schists rocks (1992,Gh.Oaie).
After that, East-European Plate must have moved clockward, movement probably accelerated during the alpine orogenesis, Teysseyre-Tornquist ligneament being its actual south-west border.
Geophysical data (gravimetric and aeromagnetic ones) on East-European-Plate from Romania suggests a downgoing movement from the NE to the W, until it reaches the biggest deep in front of Eastern Romanian Carpathians,and up to 17 km only in Vrancea seismic area. To note that the maximum of gravity anomaly wich fallows to the west is paralel with the minimum, not following the surface geological stuctural units. Electromagnetic studies made across Eastern Romanian Carpathians, pointed out the subduction coupling between East European Plate and Alpine Plate.
Despite the fact that old plates have deep roots, and move with low velocitites (Forsyte and Uyeda,1975), the eastward push must have been amplified by the superplume, pointed out under the Western Europe (Nature, 1995).

TOPOGRAPHY AND GRAVITY ACROSS SUBDUCTION ZONES

P. Harabaglia and C. Doglioni (Centro di Geodinamica, Università della Basilicata, Via Anzio, 85100 Potenza, Italy)

Topographic and free-air satellite gravimetric profiles across subduction zones show two distinct signatures. Average low topography (about 1000 m below sea level) and pronounced gravimetric anomalies characterise west directed subduction zones. Average elevated topography (about 1000 m above sea level) and smoother gravimetric anomalies are peculiar of east- or northeast-directed subduction zones. These differences are particularly evident along the Pacific margins, but they persist also along the other subduction zones of the world in the Atlantic, Mediterranean, Himalayas and Indonesia regions. Therefore topography and gravimetry confirm the existence of two separate classes of subduction zones independently from the age and nature of the subducting slab. East- or northeast-directed subductions are characterised by low subduction angles, while west-directed subductions are characterised by much steeper angles. Preliminary models of expected density distribution within the sinking slabs, indicate that the slab pull alone probably does not account for these differences; it is possible that they are linked to the 'westward' drift of the lithosphere relative to the underlying mantle.

ESTIMATES OF STRAIN FROM OLD ITALIAN TRIANGULATION NETWORK

I. Hunstad (Istituto Nazionale di Geofisica, 00143 Rome, Italy)
P.C. England (Department of Earth Sciences, Oxford University, Parks Road Oxford OX1 3PR, UK)

The angle changes between repeated surveys of conventional triangulation network provide useful information for assessing the strain of a region. The original observations are not as precise as modern (GPS) measurements, but the long intervals of time between successive surveys compensates for the inadequacies in the data. The first order triangulation network in Italy was originally measured in the 1860's, and then re-surveyed in patches during the middle decades of this century. In the absence of scale and orientation constraints, we may determine only the shear strains γ_1 and γ_2. The predominant deformational signal in the Appennines is contraction or extension perpendicular to the chain, though small patches of shear are seen. Qualitatively, the geodetically observed strains are in agreement with the seismic strain. There is, however, significant quantitative disagreement. Estimates of the deformation rate of the Appennines from seismic data lie in the range 1-3 mm/yr, or a strain rate of $1\text{-}3\times10^{-8}$/yr when divided by the 100 km width of the belt. In contrast the geodetic strain rates are approximately 10 times more rapid than this rate.

TOMOGRAPHIC IMAGES TO TRACE THE POSSIBLE ARC-TRENCH SYSTEM EVOLUTION IN THE ITALIAN REGION

F. P. Lucente and C. Chiarabba, G.B. Cimini (Istituto Nazionale di Geofisica, 00143 Rome, Italy)
D. Giardini (Dip. Sc. Geologiche, Univ. Roma III, Italy)

We present an ACH tomographic model of the mantle beneath the Italian peninsula obtained inverting a data-set of about 5500 teleseismic repicked P-wave arrivals. The computed model extends to 950 km depth and have a satisfying resolution at least down to 800 km depth. Above the depth of 450 km, we note a well defined high velocity beneath the Calabrian Arc. This high velocity body has a dip of about 80° towards NW and extends from north-eastern Sicily to the Calabria off-shore. In the same depth range other spots of high velocity are evident in our tomograms, mainly beneath the northern Apennines and the western Alps, but no evidences of continuity among these positive perturbations are present. At depths greater than 450 km, we find that the location of these positive velocity perturbations is progressively shifted towards the Tyrrhenian basin defining a roughly continuos arc from the western Alps to the Sicily channel, while a low velocity perturbation is present in the middle of the Tyrrhenian basin. At depths of about 670 km a single spread high velocity zone occupies the most of the Tyrrhenian basin. These results suggest a complex evolution of the arc-trench system, where initially continuos subduction, progressively developed in subordinate arcs as an effect of the interaction between the differential plates motion and the heterogeneous structure of the subducting lithosphere.

THE DEFORMATION ALONG THE HELLENIC TRENCH.

A.V.Lyusina (Moscow State University, Physics Faculty, Russia)
E.V.Voronina (Moscow State University, Physics Faculty, Russia)

The Hellenic trench represent a transitive zone between the underthrusting lithosphere of the Mediterranean Sea and the overriding structures of the Cretan back-arc basin. The present-day deformation processes of this region are strongly affected by a seismogenic deformation in Greece and western Turkey. Earth crust stress-deformation state of the Hellenic trench was obtained by summarizing of the seismic moment tensors for earthquakes since 1960 to 1995 years. The seismic moment tensor for every earthquake, summary tensors of deformation and the velocity of deformation, intensity and energy of deformation were computed. The empirical magnitude-seismic moment relationship for the earthquakes of this region was calculated. The orientations of the main axes of the compression deformation and of the extending deformation were determined. The most intensive deformative processes were observed in the following parts of the Hellenic arc: western part of the coast of Peloponessus and western part of the Corinth Gulf. The dominant lithosphere deformation process of the Mediterranean Sea is the compression. The dominant deformation of the southern areas of the Aegean Sea is a extending in the east-west direction. The Hellenic arc is the complicated tectonic structure. This structure is subdivided into several segments. Every segment is characterized by different intensity, energy and orientation of the deformation. Probably, the areas of the future strong earthquakes should be bound up with the areas of the mininum of the deformation velocity.

CARPATHIAN SUBDUCTION DYNAMICS AND MIOCENE STRESS CHANGES IN THE ALPINE - PANNONIAN AREA

H. Peresson and K. Decker (Institute of Geology, University Vienna, Althanstr. 14, A-1090 Vienna, Austria)

Intraplate stress fields behind consuming plate margins depend on whether subduction occurs along advancing or retreating plate boundaries. The Miocene Eastern Alps represent an advancing plate margin where protracted N-S directed continental convergence led to collisional crustal stacking and E-directed lateral extrusion. In contrast, coeval subduction of negatively buoyant oceanic crust caused subduction retreat in the Eastern Carpathians which was responsible for back-arc extension of the Pannonian area (17-9 Ma). This geodynamic setting matches paleostresses deduced from microtectonic data. Middle Miocene ~E-W directed tensile paleostresses reflected the lateral extrusion of the central Eastern Alps and the extension of the Pannonian area, both enabled and compensated by E-directed subduction retreat in the Eastern Carpathians. Extension is expressed by huge subsidence in the Vienna- and Pannonian Basin system. Microtectonic data indicate, that tension was replaced by E-directed compression between 9-5.3 Ma suggesting that soft collision replaced subduction retreat in the Eastern Carpathians due to thick European crust entering the subduction zone. Increased compressive stress induced downward flexure of the Pannonian lithosphere (continued subsidence), and uplift and erosion of the marginal areas of the Pannonian Basin system (Styrian-, Vienna Basin). In the last 5 Ma the N-S to NW-SE directed compression was established.

LATE CENOZOIC EVOLUTION OF THE MEDITERRANEAN RIDGE ACCRETIONARY COMPLEX.

T. J. Reston (Geomar, Wischhofstr. 1-3, 24148 Kiel, Germany)
R. von Huene, and the IMERSE Working Group (Geomar, Kiel, Germany)

We present some of the key results of the IMERSE project. Using high quality multichannel seismic data, integrated with wide-angle data, we present a cross-section through the Mediterranean Ridge accretionary complex and discuss its evolution. The crest of the Ridge appears locally devoid of evaporites: we infer that this was a high during the Messinian and hence the site of the Pre-Messinian accretionary complex. To the northeast, this is bounded by wrench-faulted basins (the Cleft basins) and a deep Messinian forearc basin (the Inner Plateau). To the southwest of the pre-Messinian accretionary complex, evaporites are underlain by a possible region of Plio-Quaternary subcretion of Pre-Messinian units. This in turn gives way to the southwest to a Plio-Quaternary wedge formed dominantly of accreted Messinian evaporites. The plate boundary lies near the base of the evaporites beneath this region, cutting down to depth to the northeast beneath the subcreted Pre-Messinian units. We propose that following standard accretionary tectonics through most of the Tertiary, the deposition of thick evaporites during the Messinian led to the development of a second wedge, comprised mainly of evaporites above a weak basal detachment at a region of overpressuring beneath the low permeability evaporites. However, at the front of the Pre-Messinian wedge, the detachment cuts down to depth, resulting in the subsurface accretion (subcretion) of Pre-Messinian clastics in front of the Pre-Messinian wedge.

MAPPING THE DEEP DEFORMATION IN THE MEDITERRANEAN REGION:A STUDY OF SEISMIC ANISOTROPY

L. Margheriti and S. Pondrelli (Istituto Nazionale di Geofisica, 00143 Rome, Italy)

Seismic anisotropy is a common property of the Earth's upper mantle, it is related to the strain field of the medium and therefore to geodynamics. Few studies of seismic anysotropy were carried out in the Mediterranean region both in collisional zones as the Pirenees and the Alps and in active subduction zones as Northern Apennines.
We present the results of Shear-wave splitting analysis at the MedNet stations; this seismic network cover the entire Mediterranean basin with stations also in North Africa where no measuraments of anisotropy were available. We try to relate fast directions and delay times to the deep structures shown in tomographic images and to the geodynamical processes in the area. The study revealed an extreme variability of the anisotropic parameters which suggests that deformation in the Mediterranean upper mantle is complex and not directly and simply related to Africa-Eurasia collision.

TOMOGRAPHIC IMAGES OF THE UPPER MANTLE STRUCTURE IN THE MEDITERRANEAN REGION.

Piromallo C. and Morelli A. (ING, Via di Vigna Murata 605, 00143 Rome, Italy)

We present tomographic images of the upper mantle below the Euro-Mediterranean region obtained by inversion of P-wave delay times from the International Seismological Centre Bulletins. We show the results of synthetic tests in order to assess the resolution of our model in terms of spatial extent and amplitude of the detected anomalies. Large-scale anomalies are well correlated with major tectonic features. High-velocity bodies are located along past and active lithospheric subduction zones along the Alpine belt: Maghrebides and Tyrrhenian slab, Dinarides and Hellenic slab, Carpathians. The Western section of the Alps has better developed fast "roots" than the Eastern. The fast anomaly of the Northern section of the Apennines confirms the hypothesis of subduction also shown by presence of intermediate earthquakes. Extensional basins (Tyrrhenian, Aegean, Pannonian) show as slow anomalies, such as volcanic areas (Central Massif, Italian Tyrrhenian province, Moroccan Atlas, Sicily Channel).

STRAIN FIELD WITHIN DESCENDING SLABS: EXAMPLES FROM THE MEDITERRANEAN SUBDUCTION ZONES

G. Selvaggi and A. Amato (Istituto Nazionale di Geofisica, 00143 Rome, Italy)

Intermediate and deep focus earthquakes occur in a few well known tectonic frames of the Mediterranean region that are the Alboran Sea, Northern Apennines, Calabrian arc, Aegean Sea, Cyprus and the Vrancea region in Romania. Currently, this seismicity is referred to subduction processes. Common associated tectonic features are differently developed extensional back-arc basins. Depth distribution of earthquake and fault plane solutions enlighten both the geometry of the descending slabs and their internal deformation. Among many evolutionary models proposed for these regions, the internal deformation of slabs provides useful constraints for such models. Forces due to active subduction, negative buoyancy, slab detachments and other mechanisms, all generate different strain field within slabs. We show examples from the subduction regions of the Mediterranean in which the joint interpretation of hypocenter distribution and the strain field determined from fault plane solutions can help in discriminating the dominant active processes.

TERTIARY AND QUATERNARY GEODYNAMICAL EVOLUTION OF THE CENTRAL MEDITERRANEAN: AN OVERVIEW OF THE PALEOMAGNETIC CONSTRAINTS

E. Speranza (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143 Roma, Italy)

In the last ten years a large number of paleomagnetic studies provided new constraints for the geodynamic evolution of the central Mediterranean. Owing to the improvement of the sensibility and measurement precision of the magnetometers, sedimentary sections, even weakly magnetized, were used as an accurate tool to determine vertical axis rotations. Moreover recent studies (rather than previous ones) focused on Tertiary and Quaternary sediments, thus providing data synchronous to the main tectonic events. I propose a critical review of paleomagnetic data concerning: 1) Corsica-Sardinia block; 2) Apennines; 3) Adriatic foreland; 4) eastern Adriatic belts. This analysis takes into account the quality of available data, considering the accuracy of datation, tectonic complications, magnetic behaviour, and reliability of field tests. It is shown that if only satisfactory quality data are considered, paleomagnetic constraints are significantly different from the ones generally assumed. The main conclusions are: 1) the amount and exact timing of the Corsica-Sardinia rotation is still poorly constrained; 2) in the Apennines each tectonic domain underwent distinct rotations, thus implying that the "rotation of Italy" is a nonsense; 3) the Cenozoic rotational evolution of the Adriatic foreland is largely unknown, and the few reliable data support a null rotation; 4) the eastern Adriatic belt north of Montenegro did not rotate, while south of Montenegro-Albania border the margin underwent a post-Oligocene 45° clockwise rotation.

SE5 Physical aspects of metamorphism

Convener: Gliko, A.O.
Co-Convener: Weber, K.

Sponsorship: EUG, ILP (International Lithosphere Program)

PHYSICAL ASPECTS OF METAMORPHIC IMPOVERISHMENT AND ENRICHMENT OF STRATIFORM ORE DEPOSITS

Yu. I. Demin (Moscow State University, Vorobyovy Hils,119 899, Moscow, Russia)

Geological studies, physical and computer simulation hydrothermal-metamorphic processes result in both impoverishment and enrichment of ore deposits. Paragenetic analysis made by author has shown that K-Ba fieldspars are formed as a result of barite-silicate e.g. sericite, chlorite, quartz and albite reactions under the influence of high temperature solutions. Unusual metamorphic paragenesis that include biotite, muscovite, anandite and Ba-bearing plagioclase are formed together with celsian-hyalophan-series minerals. We made the calculation of various models hydrothermal-metamorphic ore transformation in near contact zones of different intrusive bodies. The investigation shows that preorogenic ore knots and regenerate mineralization occur in thermostate zones of heat flows in the Earth'crust (temperature gradients are 0.1-0.3° C/m). Under temperature gradients exceeding 0. 8-1.0° C/m ores are commonly dispersed.

The present study was supported by the Russian Fundamental Research Foundation (grant 95-05-14055).

GEOPHYSICAL ASPECT OF THE NATURAL DEHYDRATION REACTIONS UNDER THE BOUNDARY PT CONDITIONS BETWEEN GRANULITE AND AMPHIBOLITE FACIES OF THE METAMORPHIC ROCKS.

L.I.Demina, Moscow State University, Department of Geology, Vorobjevy Hills,119899, Moscow, Russia.

Termodynamic calculations of the natural reactions with regard for chemical compositions of the coexistencing minerals shows, that dehydration reactions of the minerals under the PT boundary parameters between granulite and amphibolite facies depend not only on temperature, but also pressure, and comes with substantion negative volume effect. More of that ,the volume of the solid phases decreas at 17-35% accordance with initial content. Dehydration reactions cause rise p H2O in fluid. This promote decreas the melting temperature and granitization. In the natural metamorphic zoning complexes granization maximum is developed at the boundary between amphibolite and granulite facies (P=4-7 kbar, T=570-800 o C). Owing the processes of the dehydration and the granitization large layer with anomalous gualities of the rock takes plase on the depths 13-35 km. This phenomena is registrated by geophiisical methods in the recent continental collision zones.

PHASE EQUILIBRIA, DENSITY, AND ENTHALPY OF THE TERNARY SYSTEM H2O-CO2-NaCl ABOVE 300 C

Zhenhao DUAN and Mohan Seth

H2O-CO2-NaCl is the most common fluids in nature, which is involed in many geochemical processes, such as geothermal, metamorphic, hydrothermal, and diagenic activities. Accurate prediction of the phase behavior, density and enthalpy in this system is very important to (1) the understanding and simulating of the mass and heat transfer under various geochemical conditions, (2) analyzing fluid inclusion data, (3) the understanding of the fluid evolution, and (4) ananlyzing formation conditions of minerals.

Based on the equation of state (Duan et al., 1995), we have developed an efficient fortran code which is suitable for numerical simulation of non-isothermal heat and mass transfer processes in porous fracture media. In particular, the code calculates phase equilibria, enthalpy, density, fugacity, and their derivatives for systems involving H2O-NaCl-Co2 at high pressures and temperatures. It is currently being implemented into our general purpose flow simulator with encouraging preliminary results.

MODELLING OF TRANSFORM LINEAMENT WITH GRANITE-PORPHYRY MAGMATISM OVERLAPPING HYPERBARIC COLLISIONAL BELT : CASE OF THE LAPLAND GRANULITE BELT IN THE BALTIC SHIELD.

Filatova V.T. & Vinogradov A.N. *(Geological Institute of the Kola Science Centre of the Russian Academy of Sciences, Apatity, Russia).*

3D geological-geophysical model of the Lapland Granulite Belt (LGB) was designed, showing that the Paleoprotozoic granulite allochthon consist of three tectonic sets overlapping the Archean granite-gneissic basement in a front part and is searched down to a lower crust in a back. Some evidences of an intercrustal asthenolenses beneath the granulite sheets are revealed. The allochthon is crossed by the intercraton transform thrust zone along which a chain of mesoabyssal granodiorite-granite plutons and granite-porphyry subvolcanic stocks are localized in the LGB. Interdependency between a underthrusting velocity, a suture dip and a ductile lens thickness are evaluated and then a condition for a turbulence and back flows into a crustal asthenolayer are determined. Is shown that the accompaniing these phenomena thermomechanical effects together with disturbances of a stationary heat flow and abnormal heat accumulation under overlapped granulite sheets were responsible for occurrence of local thermal anomalies, caused a generation of acid magmas in the crustal asthenolayer .

CORNER FLOW CIRCULATION AND PHASE TRANSITIONS IN THE DYNAMIC EVOLUTION OF AN OROGENIC BELT

C. Giunchi and Y. Ricard (Laboratoire de Sciences de la Terre, ENS Lyon, France)

The preservation and exhumation of eglogitic facies rocks is an important observation to understand the geodynamics of orogenic processes. We aim at providing a numerical tool able to quantitatively estimate the effect of the complex interplay between the mechanical and thermodynamical behaviour and to asses under which conditions the preservation of metastable denser phases is possible. A finite-differences numerical method is used to solve the continuity, Navier Stokes and thermal equations for a newtonian incompressible fluid medium. In the model we take into account a typical forcing induced by a subduction process in a collisional environment. The evolution of different phases of the crust is followed by including into the numerical code pressure and temperature dependent phase transition. When the phase diagram is only prescribed from thermodynamics, although eclogite is formed at depth, it cannot reach the surface. In a further step we show the effect of phase transition kinetics. In that case the decrease of temperature can prevent the re-transformation of high density phases during their upwelling toward the surface. The distribution of mineral phases obtained using kinetic laws appears totally different from what could be predicted from thermodynamic considerations only. A comparison between geological data of the Alpine belt and the predictions of our model will be presented.

THERMAL MODEL FOR A HIGH-TEMPERATURE - LOW PRESSURE METAMORPHISM ASSOCIATED WITH CONTINENTAL RIFTING

A.O.Gliko (Inst. of Planetary Geophysics UIPE RAN, B. Gruzinskaya 10, Moscow, Russia)

Wickham & Oxburg (1985) were the first who linked continental rifting in a genetic association with high T/low P regional meta morphism and provided arguments (with a detailed study of Hercynian metamorphic terrain in the eastern Pyrenees) that the transient temperature conditions required for this type of metamorphism could be attained only during process of rifting. Based on these data and data on some other metamorphic complexes of andalusite - sillimanite bearing rocks (in Tien Shan and Scotlan d) the numerical model for the thermal evolution of peripheral parts of continental rift zone has been applied to the study of possible setting of the main facies series. The given thicknesses of andalusite, sillimanite and, especially, migmatite zones provide the constrains on the probable values of heat flow and duration of heating. It is shown that the real temperature gradients during the metamorphic event could be much higher than the standart estimates resulted from the ratio (T1 - T2)/ z , where z is the distanse between two isograds T1 and T2. The duration of heating in most cases did not exceed 1-2 m.y. Permeability created in the process of metamorphism is assumed to be concentrated in narrow zones corresponding to the peak metamorphic conditions. This structure of permeability (changing with time) provides the conduits for removing of metamorphic fluids and circulating of water mainly along the isograds resulting in changing of isotopic composition of oxygen but week effect on the thermal regime of the whole rock sequence.

FOLDING, AS A CONSEQUENCE OF HEATING FROM BELOW AND OF METAMORPHISM OF A SURPLUSLY WATERED SEDIMENTARY ROCK MASS, AND AS A CAUSE OF ITS DEWATERING

M.A.Goncharov (Lomonosov State University, Vorobjovy Hills, 119899, Moscow, Russia)

The following succession of processes, affecting a sedimentary rock mass in a mobile belt, is supposed: (1) deep catagenesis: low temperature (T), normal pressure (p), high content of water (w), and low permeability (r); (2) heating from below and isochemical regional metamorphism: high T, over-p, high w, and low r ; (3) density inversion due to increasing volume: high T, normal p, high w, and low r ; (4) limited rock mass convection due to exceeding critical Rayleigh number; (5) folding, fracturing, and allochemical local granitization: high T, locally low p, high r ; (6) elevation, dewatering, and erosion: low T, low p, low w, and high r. This concept is based on quantitative evaluation of parameters of processes under consideration, and on both computer and physical simulation of some of these processes.

PROCESS OF BIOTITE DEHYDRATION AND GRANULITE FORMATION

A.A. Graphchikov (Institute of Experimental Mineralogy, Chernogolovka, Russia)

Anomalies of electrical conductivity in middle and low crust were revealed with the geophysical methods. The nature of this phenomenon is associated with a dehydration of rocks at upper amphibolite and granulite metamorphism. However: 1. Hydrous silicates are stabile in large interval of temperatures. 2. Main process of granulite formation is partial melting. 3. At intensive mineral decomposition liberated water is absorbed by melt. 4. Minerals having different iron contents dehydrate and melt at different temperature.

ESTIMATION OF X(H2O) UNDER METAMORPHIC CONDITIONS BY METHODS OF MINERAL BAROMETRY

A.A. Graphchikov, A.N. Konilov (Institute of Experimental Mineralogy, Chernogolovka, Russia)

The next problems were investigated:
1. Experimental study of partial melting of biotite-orthopyroxene-quartz bearing assemblages in the system KAMFS-H_2O.
2. Experimental study of biotite (phlogopite-annite) dehydration in fluid H_2O-CO_2 (the role of carbon dioxide in metamorphism and melting)
3. Experimental investigation of biotite dehydration in the system KMFTAS-H_2O-CO_2.
4. The equation for calculation of xH_2O was derived. Higher xH_2O values were obtained for several charnockites of India and Sri Lanka, than those obtained by fluid inclusion studies.

PERMEABILITY, A KEY PARAMETER FOR METAMORPHISM ?

Y. Gueguen (Laboratoire de Geologie, Ecole Normale Superieure, 24 rue Lhomond, 75231 PARIS Cedex 05, France)

Temperature and pressure (confining and fluid pressure) are the main thermodynamic parameters which control both metamorphic reactions and permeability variations. It is not sufficient however to consider these parameters. At high temperatures/pressures, rocks are deforming and we examine permeability variations in a medium with no deformation, infinitesimal deformation, or finite deformation. Moreover the fluid may be or not at textural equilibrium. We consider the case of a small (infinitesimal) deformation where the matrix is treated as an elastic solid and the fluid phase is not at textural equilibrium: very large permeability variations may be expected as resulting from crack opening/closure. Experiments on dry granite samples have shown that above a critical temperature and because of thermal expansion mismatch and anisotropy, k increases strongly. The behavior of a fluid saturated granite is similar: if the thermal diffusivity is larger than the hydraulic diffusivity, the predicted fluid pressure increase is a driving force for thermal cracking. The increase in k that results will lead to fluid infiltration through the rock. Confining pressure has an opposite effect. The case of finite deformation where the matrix can be treated as a viscous rock and the real fluid phase is at textural equilibrium is a very important one. The connectivity of the fluid is controlled by surface energy. Two critical time constants t1 (for matrix deformation) and t2 (for Darcy flow) have to be compared. If t2>t1, the rock viscosity controls fluid flow. Permeability is no longer an important parameter.

THE CHANGE OF METAMORPHIC FACIES, THE KONRAD BORDER AND COMPRESSIBILITY OF ROCKS FROM THE KOLA SUPERDEEP BOREHOLE (KSD-3).

V.L.Il'chenko (Geological institute of KSC RAS, Apatity, Russia).

Investigation on the ultrasonic wave's velocity changes was carried out for KSD samples in the process of uniaxial compression in the direction of the applied pressure. Analysis of compression plots showed that at the depth interval of 7900 to 8627 m rocks of the borehole display high compressibility. The interval is located in the so-called second gneissic strata (7622-9456 m) and consist of conglomerates and gravelites representing an ancient weathering crust. In earlier investigation on elastic properties of SD-3 rocks carried out by means of acoustopolariscopy this very interval was found as the most anysotropic. Excessive strains that appeared as a result of mineral transformation at transition from greenshist facies to epidote-amphibole facies of metamorphism, appear to be responsible for anomalous disintegration of the rocks in this interval. Here is located subhorizontal interrupted seismic border - the so-called Konrade surface. Abnormal compressibility of the rocks at the interval testifies the availability of high pressure having caused changes in velocity properties of rocks at the Konrad border.

HIGH PRESSURE CRUSTAL MELTS: GRANULITES OR GRANITES ?

P. Jakeš (Institute of Geochemistry, Mineralogy and Mineral Resources, Faculty of Science, Albertov 6, Praha 2, Czech Republic. e-mail:jakes@prfdec.natur.cuni.cz

PT conditions of formation of granulites (solid-solid dehydration reactions) and PT condition of wet melting of granites overlap. Geochemical data on xenolith and shield granulites indicate the removal of low melting fraction and/or an effect of the dehydration reactions and removal of water. Non-depleted abundances of major and trace elements in felsic rocks with granulite (eclogite) facies mineralogy are rare. Granulite parageneses (garnet -kyanite granulites) of Variscan Europe (e.g., Bohemian Massif) are examples. Such rocks must have started to crystallize in the absence of fluid phase in granulite - eclogite facies conditions. Their generation may result from melting caused by the breakdown of OH bearing phases. Singh and Johannes (1996) have shown that the stability of hydrous phases decreases with increasing temperature and pressure and the stability curve, that has negative dT/dP slope coincides with the beginning of melting. Dehydration melting could be achieved throught the compression of OH bearing minerals either via the incongruent melting producing a melt and a residual phase(s) and or through the complete melting of OH bearing phase and reaction with the phases present. Thus relatively dry granitic melts could be produced during the continental collisions. Dry magma has higher viscosity and higher density than water bearing magma and if emplaced in deeper parts of the crust it may retain „granulite" mineralogy and undepleted granite compositions.

EVIDENCES FOR VERY HIGH TEMPERATURES IN THE LOWER CRUST OF THE ARCHAEAN/PROTEROZOIC IN-OUZZAL UNIT (ALGERIA)

M. Guiraud (Muséum National d'Histoire Naturelle, 61 rue Buffon, 75005 Paris, France)
J.R. Kiénast (Université Denis Diderot, 2 place Jussieu, 75252 Paris Cedex, France)
K. Ouzegane (USTHB, Dar El Beïda, Algiers, Algeria)

Melting giving way to granitoids generally occur in a temperature range of 650 - 850°C and corresponds to the climax of the metamorphic evolution. However, in some areas, mineral assemblages indicate that temperature above 1000°C has been reached which adresses the question of modelling the geodynamic setting of such assemblages. The In Ouzzal unit displays some of these high-temperature assemblages which are sapphirine + quartz, orthopyroxene + sillimanite + quartz, spinel + quartz and, possibly, osumilite and corundum + quartz. The petrological study suggests that the protolith is a platform-type sedimentary series with pelites, iron rich quartzites, altered mafic/ultramafic rocks and limestones. This series was affected by a two-stage evolution: a first stage at about 2700Ma is only shown by charnockitic type A granites; a second stage at about 2000 Ma corresponding to the very high temperature event responsible for the metamorphic parageneses observed today and for fluid-driven carbonatites and anorthositic magmas. The P-T evolution for this second stage is clockwise, with decompression and cooling from peak conditions estimated at about 10 kbar and at least 1100°C, suggesting the asthenospheric mantle reached the continental crust boundary.

SOME GEOLOGICAL-GEOPHYSICAL ASPECTS OF FORMATION PRECAMBRIAN GRANULITE-GRANITE COMPLEX OF CRUSTAL BASEMENT OF GAYSIN BLOCK

A.P.Ivakhnenko (Kiev University, Geological Dept., Geophysic, Vasilkovskaya Str. 90, Kiev, 252022, UKRAINE, e-mail: iap@rpd.univ.kiev.ua)

Gaysin block is disposed in central part of Ukrainian shield. This block presents standartic granulite-granite complex of precambrian granulite-granite transformation. We present geophysical (magnetic, gravitic) and geological (geochemical, geochronological, petrological, structural) data of investigation granylite-granite complex. Three main formations have been determineted for the rocks of this complex of the Gaysin block, including: (1) proper granulitic (enderbitic-charnockitic) the Berdychiv formation; (2) dioritic the Sobit formation; (3) granitic the Uman' formation. The research of granulite-granite interaction. In relation to change geological processes in time and space are demonstrated. The regularities of granylitic-granitic formation depending on time of generation, genesis deep and tectonic stresses have been established. Thus, structural and substance evolution precambrian granulite-granite complex was determinated.

ABOUT THE POSSIBILITY OF THE USE SERPENTINITE'S PHASE TRANSITIONS FOR TRASING THEM IN THE EARTH'S CRUST.

Yu.V. Khachay, V.V. Bachterev, O.A. Hachay, V.S. Druzhinin (Institut of Geophysics UB RAS, Ekaterinburg, 620216, Amundsen St.,100,Russia)

As a result of experimental research with use of a new method of impulse cathod luminiscence and measurements of electrical resistance it had been found out new areas of phase transitions in serpentinites of different composition at temperatures (200-600)C and normal pressure, which are accompanied by sharp on 2-3 order increasing of electrical resistance, and (from published data) decreasing of thermal conductivity.
Constructed on the basis of numerical modeling the 2D thermal section of the lithosphere along Sverdlovsk DSS profile, which crosses the Ural's structure, has allowed with the account of seismic results to allocate the space areas of probable serpentinite localization at temperatures phase transitions.
Received on the basis of direct problem solution of electromagnetic sounding the estimations of apparent electrical resistance distribution have shown an opportunity of identification and registration of these zones. So there is a possibility to trace serpentinite zones in the Earth's crust, which is necessary for studing of dynamic processes in the lithosphere,by complex geophysical data.

LEUCOGRANULITE-GRANITE LINKS IN THE BOHEMIAN MASSIF

Jana Kotková, Czech Geological Survey, Klárov 3, Praha 1

Variscan leucogranulites and granites of the Bohemian Massif have largely similar physical properties (apart from deformation of the former observable on reflection seismics images and low radioactivity). Therefore their presence in deeper crustal levels cannot be unequivocally distinguished by geophysical methods.
Mineral assemblages of leucogranulites (kyanite - ternary feldspar ± garnet) are consistent with high temperatures and pressures of their formation (14 - 15 kbar, 850-950°C), i.e. above both the experimentally determined curves of Bt-out dehydration melting reaction and the wet solidus of muscovite granite. Granulites contain scarce long prismatic zircons of magmatic origin, showing Y depletion in their outer zone. Presence of garnet inclusions in zircon and HREE depletion in some garnet rims are consistent with their contemporaneous growth. Together with P-T data, this indicates that the peak assemblage formed under granulite-facies metamorphic conditions associated with partial melting.
Geochemically leucogranulites correspond to high-K strongly peraluminous S-type granites, with composition close to granite minimum and undepleted upper crustal element abundances (vs. Th, U) . Their REE distribution patterns are comparable to those of peraluminous crustal melts derived experimentally from pelitic source.
In view of these and also dating and textural data, possibilities of melting and crystallisation under lower crustal/mantle conditions producing leucogranulites and/or granitic protoliths for these rocks are considered.

NEW DATA ON THE PHASE DIAGRAM OF CALCITE

R.M.Nasimov (United Institute of Physics of the Earth, Russian Academy of Sciences, Bol'shaya Gruzinskaya 10, Moscow, 123810,Russia)

Natural samples of monocrystalline calcite were studied in an internally heated cylinder-piston assembly up to 1000 K and 1.5 GPa. Pressures of calcite I - calcite II - calcite III transitions are determined from room-temperature measurements of ultrasound velocities of waves V_p and V_S. P-wave travel times were measured in cyclic isothermal (high-temperature) and isobaric experiments from phase diagram interceptions. The travel times change considerably across the phase interface. The pressure and temperature values of the phase transition, obtained at temperatures above 400 K, show disagreement with earlier data on the phase diagram of calcite. A new interpretation of the slope of the calcite I - calcite II curve at these temperatures is offered.

PROGRADE SAPPHIRINE GRANULITE ISLANDS IN THE AMPHIBOLITE FACIES PART OF TRANSITION ZONE: HAUGLANDSVATN, SOUTHERN NORWAY

T.G. Nijland (Rooseveltlaan 964, NL- 3526 BP Utrecht)
D. Visser (Univ. Museum Utrecht, PO Box 2055, NL-3501 AB Utrecht)
J.L.R. Touret (Department of Petrology and Isotope Geology, Vrije Universiteit, De Boelelaan 1085, NL-1081HV Amsterdam)

Amphibolite to granulite facies transition zones are generally progressive (scale of few kilometers), whether they are prograde or retrograde. However, in several areas, isolated granulite facies islands occur scattered over the amphibolite part. As regional temperatures are mostly significantly higher in granulite than in amphibolite facies, these islands are often interpreted as remnants left over after regional retrogression.
In the case of the Hauglandsvatn occurrence (Bamble sector, Southern Norway), despite the small size (100 m. at most) of the outcrop and the temperature difference recorded by mineral thermometers (about 200°C), the transition from amphibolite to the sapphirine-orthopyroxene bearing granulite appears to be prograde. The granulite facies assemblage developped at the expenses of biotite in the regional foliation, still leaving preserved biotite rimmed by a continuous corona of orthopyroxene + K-feldspar. Radiating sapphirine crystals overgrow the foliation, sometimes as fine grained symplectites of sapphirine and spinel. Fe-Mg exchange thermometry on spinel-symplectite pairs record temperature of 904+/-16°C, against 700-750°C in the surrounding amphibolites.
Either contact metamorphism or focussed fluid activity can explain such "hot spots" in the regional environment. The last hypothesis is supported by the occurrence of synmetamorphic salt-bearing aqueous inclusions (brines).

GRANITES AND GRANULITES TROUGH THE GREEN-STONE BELT METAMORPHIC EVOLUTION

L.L. Perchuk and T.V.Gerya (Department of Petrology, Moscow State University, Moscow, Russia 119899; e-mail: llp@geol.msu.ru)

Evolution of green-stone belts (GSB) through low grade metamorphism to the formation of tonalite-gneiss domes at the final stage leads to appearance of granulite belts (GB) often intruded by granites. Available data show that GB are more felsic and younger than the cratonic rocks against which they are tectonically juxtaposed. GB located between Archean cratons produce clear metamorphic zonation in the cratonic wall rocks adjacent to a "hot granulite diapir". All those suggest that the GB are genetically related to cratonized GSB, and may have moved from the lower crust to shallower crustal levels at a late stage in the evolution of the GSB. The theoretical background for such a model involves a crustal convective mechanism involving the gravitational re-distribution of rocks in the GSB as a result of mantle derived heat/fluid flow. This model was tested through careful field and laboratory studies involving studies of metamorphic zoning along the contact between GSB and GB, and the study of successive magmatic events, deformational histories, spatial variations in PT-paths, isotopic age correlations, etc. At present there are a few well documented studies on the relationship between GSB and GB. The Lapland GB (the Kola Peninsula), the Kanskiy GB, and the Limpopo GB (South Africa) provide evidence for the gravitational redistribution process (Perchuk et al., 1992).

EVOLUTION OF PT-CONDITION IN THE LAPLAND-BELOMORIAN COLLISIONAL BELT: PETROLOGICAL RECORDS AND DIGITAL SIMULATIONS BASED ON THE HYDRODINAMIC THEORY OF LUBRICATION

Filatova V.T., Petrov V.P., Vinogradov A.N. (*Geological Institute of the Kola Science Centre of the Russian Academy of Sciences, Apatity, Russia*)

In the Lapland Granulite Belt (LGB) a multiphase hystory of formation and transformation of both structural patterns and mineral associations in granulites and associated rocks were revealed by geological, petrological and geochemical methods at age interval 2.4-1.7 Ga. From data recorded by different mineral geothermobarometers the P-T trend was searched in a range of T 300 - 800° C and P 5 - 12 kbars, but a presence of thin dispersed moissanite and diamond inclusions in granulites can be considered as a sign of a more higher stress in local hyperbaric zones. To evaluate a probable paleopattern of P field in LGB a digital simulation was performed with application of the hydrodynamic theory of lubrication to the simplified threlayerd rheological model of the Kola-Belomorian collision belt. Is shown, that during a main collision phase a spatial distribution of P values into a crustal asthenolens was non-linear. In the conjuction zone between collided megablocks an abnormal increase of P was simulated. According to digital model the hyper-pressure could reach up 50 kbars and contemporaneous abrupt growing T up to 200-300°C above local phone was able too. A range of P and T variation is controled by values of an underthrusting velocity as well as of a suture dip. As evaluated an increase the dipping angle of 1° or the velocity of 0.5-1.0 cm/year have to cause the P anomaly of 20 - 40 kbars.

PROBABLE NATURE OF THE JUMP OF THERMAL CONDUCTIVITY ON MOHO BOUNDARY

G.I.Petrunin, V.G.Popov (Physics Faculty, Moscow State University, 119899, Moscow, Russia)

Metamorphic processes connected with the appearance of hydroxide groups in a lattice of mineral decrease the heat transfer intensity. This is caused by the increase of centers of phonon scattering on fluctuations of additional masses and elastic constants in a crystal. The density of these fluctuations rises with a complication of chemical composition. The example of such process, which proceeds at temperature below 500°C and has wide spreading, is the serpentinization of hyperbasites that perhaps determine the Moho boundary under oceans. In this work the thermal parameters of 15 samples of serpentinized ultrabasites were measured at temperature 300-800°K. Analysis of the obtained results allows us to make a conclusion about the influence of serpentization degree on thermal diffusivity and thermal conductivity of ultrabase rocks. Thus, thermal conductivity of hyperbasit serpentinized up to 70-90% is twice lower than that of their nonchanged analogues. Based on the experimental material and theoretic appreciation of the jump of thermal conductivity on Moho boundary, we have shown that thermal conductivity behavior data is consisted with our assumptions.

DYNAMOTHERMAL (IN OROGENY) AND BURIAL (EXTENSIONAL) METAMORPHISM: ALTERNATIVE MODELS

V.Reverdatto, O.Polyansky, V.Anan'ev & V.Sheplev. Inst.of Geol., Geophys. & Mineral., Siberian branch of Russian Acad.Sci., Novosibirsk, Russia

Dynamothermal metamorphism in mobile belts of the crust is related to orogeny and acid magmatism and is conditioned by elevated heat flow from the mantle. This process has been studied in terms of two mathematical models: magmatic basic intrusion and fluid flow; the former is considered more acceptable for the explanation of dynamothermal metamorphism.An alternative process (not counting subduction) can be caused by stretching, extension and thinning of the lithosphere, ascent of hot asthenosphere, isostatic reequilibration, subsequent cooling and thermal contraction; as a result, burial metamorphism of the sedimentary infillings of extensional basins happens. Mathematical modelling of this metamorphism at various rates and regimes of lithospheric extension and posterior erosion has allowed us to investigate the subsiding dynamics and thermic history exemplified with some specific basins. All these models were used to determine and compare PT-t paths in the alternative types of metamorphism; in this connection, counter- and clockwise PT- evolution paths have been analyzed.

METAMORTHIC FLUID MOVEMENT IN THE LOWER CRUST

E.I. Suetnova(United Institute of the Physics of the Earth,RAS, B.Gruzinskaya 10 Moscow 123810 Russia)

Recent geophysical studies indicate presence of fluids in the lower crust in areas of enhanced electrical conductivity and seismic reflections, allied to the presence of free fluid that is thought to accompany metamorphism. As a crust heats up /thermal activisation, overthrusting/, decarbonation and dehydration reactions cause alteration minerals to release volatiles. A new interconnected pore space filled by fluid phase is organized. Free metamorphic fluid tends to propagate upward by porous flow because of density difference and compaction of rock matrix. Thermomechanical model of metamorphic fluid movement inside a crust is suggested. The system of governed equations describes thermal regime of dehydration, upward movement of metamorphic fluid by porous flow and compaction of the crust media. Governing system of equations is the "dynamic system". Calculations of fluid pressure lead to conclusion that metamorphic fluids migrate into the upper crust by hydraulic fractures, because of fluid pressure riches the critical value soon. Such a crack is unstable and metamorphic fluids penetrate into the surface episodically. The depth level of fracturing is determined by the thermal evolution of the crust.

Sergei A. Ushakov [1] & Irina S. Ushakova[1]

BLACK SEA LITHOSPHERE SUBDUCTION UNDER CRIMEA AND WEST CAUCASUS

[1] Lomonosov Moscow State University,Earth Sciences Museum and Geography Department Moscow, Russia

On the basis of geomorphological and geophysical data analysis including seismic, gravitational and geomagnetic ones geodynamic nature of the Caucasus and Crimea mountains is examined. It is shown that the West Caucasus mountains (from Novorossisk town up to Tuapse and Sochi towns) are the summit of big accretionary prism. The prism goes on to form at present.The very young sediment folds are not following in the Black Sea floor relief but are distingushed in sediment cover structure in 100-120 km westwards from off north-east Black Sea coast. The West Caucasus mountains accretionary prism is forming in the process of the Black Sea area diminition and Black Sea lithosphere subduction under the Caucasus with the velocity less than 1 cm/year.

The Crimea mountains are not isostaticaly equilibrated. Their maximum altitude is closed to 1.5 km ; the isostatic anomalies value is + 150 mgl. Southwards from the Crimea south coast parallel to it there is the negative anomaly zone where minimum anomaly value is eaqual to - 200 mgl. An existence of large conjugate positive and nagative anomalies allowed us to conclude that the Crimea mountains just as the mountains is result of the Crimea continental lithosphere upthrusting upon the Black Sea oceanic lithosphere. The Black Sea lithosphere subduction is proved by seiamic data (Lazar I. Kogan) . According these data in minimum isostatic anomalies zone within the Black Sea lithosphere basment relief under sediments the deep buried trough is detected.

ANOMALOUS ZONES OF THE DEEPER CRUST AS NON-EQUILIBRIUM FLUID ENHANCED METAMORPHIC STRUCTURES

M.V. Rodkin (Geophysical Center, Molodezhnaya 3, 117296, Moscow, Russia, rodkin@wdcb.rssi.ru), I.O.Bayuk (OIFZ, B. Gruzinskaia 10, 123810, Moscow)

Deep crustal high conductivity and lower velocity zones are interpreted ordinarily as free fluid containing zones. This model meets however difficulties in explanation of higher (than could agree with geological data) deep fluid concentration needed to cause the observed anomalies in the seismic velocities and conductivity and in the explanation of the stability of fluid containing zones at the geological time scale. The difficulties take place if sub-equilibrium structure is typical of rocks and fluid intrusions. We suggest to treat the anomalous zones of the deeper crust as zones of active metamorphism in which deep fluid acts as a catalyst. In this case the non-equilibrium fine-grain structure of the rocks and non-equilibrium high-penetrative regime of the fluid take place. We model this structure using the generalized singular approach (GSA) method. The elastic and conductivity tensors as well as seismic velocities were calculated for very different and complicated models of the media including hierarchical model. The results obtained display good agreement with empirical data.

GRANULITE METAMORPHISM: FLUID ABSENT AND FLUID DOMINATED PROCESSES

J.L.R. Touret (Department of Petrology and Isotope Geology, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands)

As soon as regional temperatures reach melting conditions for a given protolith, granulite metamorphism will develop if H2O activity remains low. This may occur in an internally buffered rock system for relatively dry protolith, if H2O released during mineral breakdown is either dissolved in H2O unsaturated melts, or is chemically destroyed (notably by reacting with organic carbon). However, compelling evidence, from both fluid inclusions and mineral textures, show that in many cases, granulite metamorphism did occur in the presence of externally derived fluids, sufficiently abundant to dilute any free H2O and maintain its activity at values of the order of 0.1 or 0.2. Two fluid types have been identified: high density CO2 and concentrated saline solutions (brines). They occur in granulites from any age of structural setting, notably in the roots of former supercontinents, notably Rodinia and Gondwana (age of granulite metamorphism: 1000 and 500 My, respectively). Both fluids remained immiscible during the whole metamorphic evolution, with important metasomatic effects (feldspathisation) for the brines. Most CO2 is magmatic (mantle derived); some brines at least derive from former sediment waters, but a magmatic origin cannot be excluded for others. Fluid movements after peak metamorphism, with important consequences on the rheology of the lower crust, are governed by the relations between fluid molar volume and regional P-T conditions. Because of the steeper slope of aqueous isochores, brines are mainly mobile during periods of isobaric cooling (anticlockwise P-T paths), CO2 during isothermal decompression.

THE CONTINENTAL LOWER CRUST: STRUCTURAL AND LITHOLOGICAL CONSTRAINTS.

T. Weiß (Institut für Geologie und Dynamik der Lithosphäre, Goldschmidtstr. 3, D-37077 Göttingen, Germany, tweiss@gwdg.de)
S.Siegesmund (Institut für Geologie und Dynamik der Lithosphäre, Goldschmidtstr. 3, D-37077 Göttingen, Germany,)

The relationship between seismic anisotropy and crustal reflectivity is poorly understood. Deep seismic reflection studies have shown that "lamellae" are a widespread reflectivity pattern of the lower crust in the Hercynian range of Western Europe. Recent seismic surveys of the Urach geothermal anomaly (S-Germany), which is known as a classical example of the lower crust lamellae, provide direct evidence of in-situ shear wave splitting implying that the lower crust is anisotropic. To quantify orientation and magnitude of the observed shear-wave splitting phenomena it is significant to investigate whether the lamellae are the result of varying lithologies or if they are strain-induced. The effect of different lithologies expressed by a dominance of more felsic or mafic rocks and their effective anisotropy has been investigated. Averaged 3D-elastic tensors for the respecitve lower crustal sections (Ivrea-Zone, Calabria, etc.) with a high resolution and a varying layer thickness were modelled. The influence of different averaging techniques (e.g. Voigt, Backus etc.) will be presented. The results of the previous models are investigated in detail for their application to the lower crust in Southern Germany.

DENSITY INHOMOGENEITIES OF THE EUROPEAN-MEDITERRANEAN UPPER MANTLE INFERRED FROM LARGE-SCALE 3-D GRAVITY MODELLING

T.P.Yegorova, V.I.Starostenko and V.G.Kozlenko (Institute of Geophysics, Nat. Acad. Sci., Pr.Palladin 32, Kiev 252680, Ukraine)

Residual gravity anomalies over the European-Mediterranean region were determined on a 1°×1° grid by subtracting the calculated gravity effect of the density crustal model from the observed gravity field.This 3-D model is based on a generalised maps of the top of the basement and the Moho and comprises of two regional layers of varying thickness with a lateral variation in average density: the sedimentary cover and the crystalline crust.The mantle origin of residual gravity anomalies is confirmed by their close correlation with upper mantle heterogeneities, shown by sesmotomography and geothermal investigations. Residual gravity field was inverted into the distribution of density anomalies within the uppermost mantle layer bounded below by the 200 km depth. The high density heterogeneities were found in the upper mantle below the Alps, the Adriatic plate and the Calabrian Arc. The correlation of these domains with both the high velocity heterogeneities in the upper mantle and a low-temperature regime is here interpreted by the presence of cold dense matter of subduction zones in the upper mantle beneath these structures, manifested by thickened lithosphere and the "roots" beneath these units.

TECTONICS OF THE EASTERNMOST MEDITERRANEAN: GEOLOGICAL AND GEOPHYSICAL DATA ANALYSIS.

V.V.Yutsis, O.A.Smoilovsky (Department of Dynamic Geology, Geological Faculty, Moscow State University, 119899, Moscow, Russia)

The structure of the easternmost Mediterranean is very complex and variable and has a convergence/collision between African and Eurasian lithospheric plates as a tectonic setting. The analysis of geophysical fields and seismic data shows that it is characterized by complex relationships of microplates and terrains which have different structure and genesis. The kinematics of these units defines the configuration of the junction zone of the African, Arabian and Anatolian plates, the intensity and peculiarity of modern subduction in the Cyprus segment of the Hellenic island-arc system. Due to collision between Africa and Eurasia and southwestward movement of Anatolia there are several geodynamic situations between existing structures: extension, block compression and strike-slip movements. These types of tectonic processes cause thrusting and rotation of microplates. It is possible that these microplates can be devided into suboceanic and subcontinental ones by their structure. It is suggested to explane such complex structure of the easternmost Mediterranean by the presence of several microplates in the framework of multilayer plate tectonic approach. In this connection, it can be supposed that the transitional zone between major plates extends southward of Cyprus right to the African continental slope and all area of easternmost Mediterranean is involved to the process of collision.

SE6 Earthquake precursors

Convener: Biagi, P.F.
Co-Conveners: Kingsley, S.P.; Parrot, M.

THE QUALITY OF A SEISMIC PRECURSOR: STATISTICAL SIGNIFICANCE AND RELIABILITY

D.Albarello (Dept. of Earth Sciences - University of Siena - Via Banchi di Sotto 55, 53100 Siena - Italy)

A number of statistical procedures have been so far proposed to assess the quality of a seismic precursor from past experience. The variety of approaches may lead to quite different evaluations of the precursor on the basis of the same data set. These discrepancies are in most cases due to the different purposes which actually underly the proposed approaches. In order to clarify this problem, the two fundamental strategies devoted to the empirical validation of a seismic precursor will be discussed in the frame of a coherent probabilistic formalization. The first strategy refers to a "frequentist" interpretation of probability and is devoted to evaluate the probability that the observed correlation between the past precursor occurrences and corresponding earthquakes can be attributed to chance (Statistical Significance). The second one refers to a "Bayesian" approach and aims at the evaluation of the "degree of belief" associated to the hypothesis that a future precursor occurrence will be actually followed by an earthquake (Reliability). Due to the different purposes, the estimates of significance and reliability will be based on different procedures and will produce different and not comparable evaluations of the precursor under study.

PERTURBATION OF ATMOSPHERIC CONDUCTIVITY AS A CAUSE OF THE SEISMO - IONOSPHERIC INTERACTION

L. Alperovich (Department of Geophysics and Planetary Sciences, Tel-Aviv University. Tel-Aviv, Israel)
E. Fedorov (Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia)

The resistivity of the air atmosphere is assumed to decrease by 1-2 order before earthquakes due to the emission of long living radioactive products (like radon with the period of 3.8 days). As a result, the region with extremely high atmospheric current density appears ($j \sim 10^{-10} \div 10^{-11} A/m^2$). Two possible channels of an influence of atmospheric current on the ionospheric D-layer has been considered: 1) galvanic mechanism due to current flowing through nonhomogeneous media and 2) Joule heating of the low ionosphere. An estimation of the electron generation rate proves that the increasing of the background vertical atmospheric electric current by two orders produces $\sim 1 cm^{-3} sec^{-1}$ electron influx into D-region above an seismic area. Joule heating increses the integral atmospheric conductivity in the seismic area by $1 \div 2$ order thus resulting enhancement of the electron ionospheric temperature up to $10^3 \div 10^4 K$. Such electron heating leads to growing of the electron collision frequency $\nu_{en} \sim T_e$ by $1 \sim 1.5$ order and, as an effect, to essential drop of the ionospheric conductivity above the place of developing earthquake.

WAVELET TRANSFORM AS A TOOL FOR DETECTION OF GEOMAGNETIC PRECURSORS OF EARTHQUAKES

L. Alperovich (Department of Geophysics and Planetary Sciences, Tel-Aviv University. Tel-Aviv, Israel)
V. Zheludev (School of Mathematical Sciences, Tel-Aviv University, Tel-Aviv, 69978, Israel)

US geomagnetic network data were used to reveal ultra low frequency (ULF) waves prior to the occurrence of strong earthquakes, such as $M = 7.0$ Loma-Prieta, California earthquake. We have applied discrete and continuous wavelet analysis trying such libraries of wavelets as Daubechies and spline wavelets, and Symmlets of different orders. We were looking for ULF perturbations whose intensities near the earthquake location override those at any other observation site available. Moreover, the perturbations sought should spread out from this area. For this purpose methods of data processing had been developed based on an appropriate thresholding of wavelet coefficients and a special reconstruction technique. Results are: 1) Clear short wave-trains with period of $\approx 10\, min$ were detected within about 1.5 day before the earthquake. 2) These signals were observed simultaneously at different observation sites with maximal intensity of $5\, nT$ at the nearest to the earthquake site (Fresno). 3) Propagation velocity of the perturbations is $\approx 5 km/sec$. 4) We have compared simultaneous ground-based and GOES-7 satellite ULF geomagnetic data as well. The phenomena have been recogised with a various wavelets, but the best performance was achieved using spline wavelets of 8^{th} order and Symmlets of 10^{th} order. An explanation on the propagation features of these perturbations is discussed.

WAVELET APPROACH TO EXTRACTION OF TSUNAMI CAUSED EVENTS FROM GEOMAGNETIC DATA

L. Alperovich (Department of Geophysics and Planetary Sciences, Tel-Aviv University. Tel-Aviv, Israel)
V. Zheludev (School of Mathematical Sciences, Tel-Aviv University, Tel-Aviv, 69978, Israel)

The energy emitted by an under-water earthquake and the following run-up of the ocean surface produces atmospheric pressure oscillations of the period $10 \div 30 min$ which can reach ionospheric levels. It can initiate a motion in the ionosphere and, as a result, excite long-period electromagnetic perturbations. A distinguishing feature of these waves should be time delays which increase as the wave spreads away from the tsunami origin. We have applied an original technique of spline-wavelet packet analysis to the US geomagnetic network data. A thorough examination of numerous trains has revealed the special kind of perturbations in the form of isolated trains of duration about 1 hour and containing pulses of 15 min period. For example, the magnetic train associated with Hawaii tsunami (26.06.1989, at $3^h27^m UT$) arose 2 – 3 hours after the first under-water shock, when the tsunami wave reached a shelf zone and its run-up became large enough to excite the geomagnetic perturbation. The wave velocity was about 100 km/min. These results are discussed in light of the theory of slow hydromagnetic waves in the E- and F-ionospheric layers.

EARTHQUAKE STATISTICS FROM SELF-ORGANIZED CRITICALITY

Per Bak (Niels Bohr Institute, Blegdamsvej 17, Copenhagen, Denmark

Large dynamical systems tend to organize themselves into a critical state with events over a wide range of sizes, given by a power law distribution. At the critical state, the dynamics can be represented by a fractal in d spatial and one temporal dimension. Earthquakes may be the most spectacular example of this phenomenon. The Gutenberg Richter law is a direct fingerprint of criticality. The fractal structure of the critical state has some consequences for earthquake statistics. For instance, the time interval between two subsequent earthquakes, and the time interval between any two earthquakes, are given by power laws with the two exponents always adding up to 2. A recent analysis of earthquakes in California by Ito confirms this result. Ito found the values 1.4 and 0.5 for the two exponents, respectively. The power laws imply that the longer time since the most recent earthquake, the longer one can still expect to wait for the next earthquake! Incidentally, the delays of busses and trains obey the same statistics. This behavior sharply contrasts the usual relaxation-oscillator picture where earthquakes are more or less periodic, but agrees with empirical observations in California and the New Madrid earthquake zone.

GEOPHYSICAL AND GEOCHEMICAL PARAMETERS JOINTLY MONITORED IN A SEISMIC AREA OF SOUTHERN APENNINES (ITALY).

V. Cuomo and G. Di Bello (Dip. di Ingegneria e Fisica dell'Ambiente, Università della Basilicata, Potenza, Italy).
J. Heinicke and U. Koch (Saxon Academy of Sciences, Leipzig, Germany)
V. Lapenna and S. Piscitelli (Ist. di Metodologie Avanzate di Analisi Ambientale. CNR, Tito (PZ), Italy)
G. Martinelli (Servizio Cartografico, Regione Emilia Romagna, Bologna, Italy)

Since 1991 a research activity devoted to the analysis of geophysical and geochemical time series jointly monitored in a test site located in Southern Italy is carried out. After a preliminary screening of spatial and temporal patterns of geochemical and geophysical phenomena observed in the investigated area, two multiparametric automatic stations, able to detect possible precursory phenomena. have been set up close to anomalous fluid emissions in Tramutola and S. Cataldo The stations are equipped with sensors suitable for CO_2, ^{222}Rn, electrical conductivity in water, temperature and self-potential probes. The aims of the research activity are: a) to obtain a complete data-base of precursory time series in order to apply statistical methods to discriminate anomalous patterns from background noise; b) to link the geophysical and geochemical signals. A preprocessing of the time series was carried out to study the correlation between the observed time series and the meteo-climatic variables. Finally the first results regarding the possible correlations between anomalous patterns in precursory parameters and the local seismic activity are analyzed and discussed.

REGISTRATION OF EARTHQUAKE PRECURSORS USING LASER MEASUREMENTS OF EARTH CRUST DEFORMATIONS.

S.N.Bagayev V.A.Orlov (Institute of Laser Physics, Siberian Division Russian Academy of Science, pr. Lavrent'eva 13/3, Novosibirsk, Russia)

Experimental results obtained in the adit in Baikal Lake rift region with the use of heterodyne He-Ne laser dephormograph are analysed. A number of effects registered on the eve of regional earthquakes and strong remote seismic events (Spitak 1988, Kobe 1995) are considered. Opportunities of long-base measurements (1 - 5 km) of Earth crust deformations in atmosphere with the help of CO_2 laser systems are discussed.

HYDROGEOCHEMICAL ANOMALIES IN KAMCHATKA (RUSSIA)

P.F. Biagi (University of Bari, Italy), F. Bella, F. Cozzi, G.Della Monica, R.Scandone, V. Sgrigna (University of Roma III, Italy), M. Caputo (University of Rome "La Sapienza", Italy), A. Ermini (University of Rome "Tor Vergata", Italy), G. Martinelli (Regione Emilia-Romagna, Italy), E.I. Gordeev, Y.M.Khatkevich (KEMSD, Geophysical Service of RAS, Petropavlovsk-Kamchatsky, Russia), D. Zilpimiani (Georgian Ac. of Sciences, Tbilisi, Georgia).

Data concerning discharge, temperature, pH, melted iones and gases from underground waters obtained in Kamchatka during the last twenty years are presented. Some hydrogeochemical parameters reveal clear coseismic and postseismic anomalies on the occasion of the five earthquakes with magnitude 6.5, occurred at distances shorter than 200 km from the measurement site. Hydrogeochemical parameters from another zone show anomalies on the occasion of three of the quoted earthquakes. Such earthquakes are characterized by the highest values of the deformation parameter and the corresponding anomalies are preseismic ones, starting from 1 to 4 months prior to the earthquake. Finally, some hydrogeochemical parameters from a third zone show clear preseismic anomalies on the occasion of just one of the previous earthquakes. The location of this last one is on the mainland while, generally in Kamchatka, hypocentres of earthquakes are below the sea. A model able to explain some aspects of the observed phenomena is proposed.

EQUATORIAL IONOSPHERE ANOMALIES RELATED TO EARTHQUAKE

Anna Depueva and Yu.Ya.Ruzhin (IZMIRAN,Troitsk-town,Moscow,142092, RUSSIA)

The whole complex of physical phenomena in near Earth environment, namely ionospheric plasma reaction, is observable during the preparation stage of the future earthquake. Particularly, in the majority of recent publications electron density at 300 -1000 km height enhancement over the preparation zone 2 - 3 days before the event is emphasized.This effect is evident at night hours and assumed as one of the seismoionospheric precursors.We would like to present some results of ionospheric data retrospective analysis before a few strong (M>5) earthquakes with their epicenters situated in a vicinity of the dip equator near the coasts of Peru and New Guinea. There are FoF2 data measured by ionosondes on board of ALOUETTE1 and ISS-b satellites, and also FoF2 monitored by Talara, Huancayo, La Paz, Vanimo, Port Moresby, etc. regular ionospheric stations.
We came across with the phenomenon opposite to usually observed: FoF2 values before earthquakes were less than after them, less than FoF2 measured outside the preparation zone boundary, and comparatively to median values.
Up to now the question of the differentiation between seismoionospheric precursors manifestation in conjunction with epicenter location was not on the agenda. On our mind the absence of correspondence between our results and usual point of view is not random. It is the result of specific physical processes taking place in low-latitude ionosphere. It seems that electric field of lithospheric origin being transformated to ionospheric heights cause the phenomenon like well- known "fountain- effect" which is regularly observable at low-latitude ionosphere. It in turn can lead to FoF2 trough, or "bite-out", over the epicentral zone as well due to plasma ExB drift .Further studies of above-said effect will be useful from the point of view of strong earthquake prediction by means of near Earth space monitoring.

SEISMICITY CYCLES IN THE MT.VESUVIUS AREA AND THEIR RELATION TO SOLAR FLUX AND THE VARIATIONS OF THE EARTH'S MAGNETIC FIELD

G. Duma (Central Institute for Meteorology and Geodynamics, Hohe Warte 38, A-1191 Vienna, Austria)
G. Vilardo (Osservatorio Vesuvano, Via A. Manzoni, 249, I-80123 Napoli, Italy)

Since 1972 the seismic behaviour of Mt.Vesuvius volcano has been continuously monitored with consistent instrumentation. During the last 25 years more than 7800 tremors were detected ($-0.4 \geq M_D \geq 3.4$).
An analysis of earthquake occurrence has been performed with respect to diurnal, annual and long term seismicity changes. Periodogram analysis suggests very dominant periodicities of earthquake occurrence. First, seismic cycles are compared with those of Solar Flux (2800MHz) and atmospheric data (rainfall, atmospheric pressure). The comparison indicates a remarkable relation among the periods observed in the seismic, solar and atmospheric time series.
On the other hand it turns out that the systematic variations of the Earth's magnetic field show very similar features when compared with the changes of seismic activity, too. This phenomenon has been already stressed extensively by Duma (1996) at the XXV General Assembly of the ESC in Reykjavik and demonstrated for several earthquake zones around the world. The analysis of seismic event frequency in the area of Mt.Vesuvius confirms very impressively those former results.

RADON AS EARTHQUAKE PRECURSOR ?

M. Garavaglia, C. Braitenberg, M. Zadro (Dep. of the Earth Sciences, via Weiss 1, 34127 Trieste, Italy)

The measurement of Radon emanation from soil in seismic areas has given promising results in the research of seismic precursor. An important aspect in the precursory research is to have as complete knowledge as possible of the normal behaviour of the time variation of the concentration measured, in order to clean the data from all the known sources causing a non-seismic signal.
Since October 1994, a station for the joint monitoring of the horizontal deformation, vertical tilt and radon emanation from the soil operates in a natural cave located in a highly seismic area in NE-Italy. The cave, 60 m deep and with a thermal annual variation of 1 °C, prevents the station of all the anthropic disturbances. In the near future we intend to add a second station for the measurement of radon concentration in water. This second station, realised at the I.N.G. of Rome, will be installed in a natural sulphurous spring 20 Km far from the cave.
The aim of the research here presented is to find the correlation between the radon data with the local seismicity and measurements of deformation.
In this work the results of the preliminary analysis of Radon data, are shown. Disturbances of various cause on Radon data are found.
First of all, we have found an apparent influence of the atmospheric pressure on Radon data. The removal of this effect is performed trough a linear regression method by using external and internal pressure. Likewise we shell proceed to remove the effect due to rainfall. We also tested the correlation with the tidal forces and the analysis have shown ambiguous results.

AN IMPROVED MODEL FOR THE INTERPRETATION OF GEOCHEMICAL PRECURSOR PHENOMENA AT THE VOGTLAND-NW BOHEMIAN SWARMQUAKE REGION

J. Heinicke and U. Koch (Saxon Academy of Sciences at Leipzig, Research Group Freiberg, TU Bergakademie Freiberg, Bernhard-von-Cotta Str. 4, D-09596 Freiberg, Germany, e-mail: heinicke@physik.tu-freiberg.de)

Geochemical and hydrological data recorded at the spring water of Bad Brambach since 1989 suggest a significant correlation with the local seismicity. The radon anomalies may be related to a large number of microquakes located in a statistically defined area approximately 12 km in the east of our measuring site. The results show that the CO_2 gas emission may influence the behaviour of radon significantly. Therefore, an intensified investigation of spring gas emissions with respect to other geochemical/geophysical parameters was one consequence in the present state of earthquake prediction research.
The results are the basis for a modified model to explain the generation of geochemical/hydrological anomalies due to fluid/rock interactions in the seismogenic zone. The influence of oriented crack propagation onto the fluid migration will be discussed as one reason for the origin and the propagation of fluid pressure pulses up to the Earth's surface.

ANOMALIES IN DIFFERENT PARAMETERS RELATED TO THE M=3.9 GRAN SASSO EARTHQUAKE (1992).

A. Ermini (University of Rome "Tor Vergata", Italy).
P.F. Biagi (University of Bari, Italy)
F. Bella, G.Della Monica, V. Sgrigna (University of Roma III, Italy)
M. Caputo (University of Rome "La Sapienza", Italy)

The Gran Sasso chain is located in the Central Apennines and contains one of the largest aquifers of Central Italy. From 1986 up to now the most remarkable event was a seismic sequence that occurred on August 25, 1992 characterized by an earthquake with M=3.9, followed by several aftershocks with M≤2.0. From ten days before the main shock, the electromagnetic and seismoacoustic equipment set up in a natural cave of the Gran Sasso chain showed anomalous acoustic signals and an anomalous decrease of the natural electric and magnetic emissions. Flow rates of three springs located at the border zone of the chain showed in 1992 a clear anomaly in the characteristic cyclic trend. The tilt trend from a measurement site located in the underground laboratories inside the massif, showed also a clear anomaly in its characteristic annual trend. All these anomalies seem to be precursory phenomena of the quoted earthquake. We present a possible explanation for the observed phenomenology, considering this earthquake as induced by an anomalous variation of the Gran Sasso aquifer connected with a peculiar meteorologic situation.

ELF Precursor of Moderate M5.8 Inland Earthquake — A general approach to electromagnetic wave precursor —

M.Hata, X.Tian, I.Takumi, S.Yabashi and A.Imaizumi (Dept. of Intelligence and Computer Science, Nagoya Inst. of Tech. Gokiso-cho Showa-ku Nagoya 466 Japan)

Electromagnetic wave precursor at ELF band of 223Hz on the occasion of the M5.8 '96 East Yamanashi-prefecture earthquake in the central Japan is discussed. (1)It was monitored with a high sensitivity of sub-pico Tesla per root hertz at five locations ranging from 50km to 1000km. (2)These multi-location data supplied us a new method to analyze and to clear up precursor through a time and spatial correlation and normalization technique by making use of the received tropical thunder noise as a reference for all spots. (3)The precursor is consisted of two factors of the locally radiated signal at the preparing area and of the modification by propagation characteristic of ionosphere. (4)On the multi-observation system, we could show an effective processing method by removing large disturbances due to solar-flared radiation and nearby lightning noise. (5)Further, We proposed an idea of equivalent electric dipole model estimated on the earth surface inclusive of all kinds of physical origin. (6)Once a catalogue of parameters of intensity and source radius of the equivalent dipole model from the observed data is completed, we can estimate precursor level and detectability. (7)A preferable arrangement of sensors to forecast a disastrous M6-class inland earthquake of man power loss was determined to be 5 to 10km spacing.

EARTHQUAKE PRECURSORS IN TEMPERATURE AND WATER LEVEL RECORDS OF BOREHOLES IN TURKMENISTAN

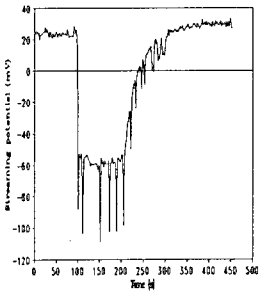
G.A. Ishankuliev (Seismological Institute, T.Berdiyev str. 20a, Ashgabat, Turkmenistan)
G. Buntebarth (Technologiezentrum, Burgstaetter Str. 6, D-38678 Clausthal-Z., Germany), V. Belikov (Hydrogeological Dept., Berzengi, Ashgabat, Turkmenistan)

Temperature and water level have been recorded with high precision in 3 boreholes since a few years. The boreholes are located near Ashgabat, 20km NNW and 30km EES of the capital, i.e. along the Kopet Dagh front fault. Attention is paid to the effect of small local seismic events with magnitudes between 3 and 5. All boreholes demonstrate that precursory phenomena can be realized with different time delay between the onset of precursory effects and the time of occurrence of earthquakes. The delay time is short, if a small eathquake occurs close to the borehole and a few weeks are determined, if the magnitude is 4 to 5 at distances between hypocenter and borehole of a few tens of km. It seems that only these boreholes exhibit precursory phenomena in the temperature records in which the water level is sensitive to the earthtides.

ANOMALOUS 0.1-0.5 HZ STREAMING POTENTIAL MEASUREMENTS UNDER GEOCHEMICAL CHANGES

Laurence Jouniaux and Jean-Pierre Pozzi (Laboratoire de Géologie, ENS, 24 rue Lhomond, 75231 Paris Cédex 05, France, email: jouniaux@magnetit.ens.fr)

The streaming potential due to fluid circulation in rock was measured on saturated sandstones. Unusual pulses were observed in the frequency range from 0.1 to 0.5 Hz: 1) when the conductivity of the injected water is decreased, 2) when the fluid flow is relatively low. These pulses are likely the result of a combination of the perturbation in the cation density near the surface and of the kinetic of the fluid flow. Possible consequences of these transient streaming potentials have been put forward to investigate the oscillatory nature of signals that could appear during the preparation of an earthquake. At the earth surface the 0.1-0.5 Hz component could be observed easier than the steady electrokinetic potential.



SWARMS EARTHQUAKES AT THE NORTH TIEN-SHAN

V.V. Kazakov,
Institute of Seismology Ministry of Scienece - Academy of Sciences
Republic of Kazakstan

We have investigation swarms of weak earthquakes at the North Tien-Shan (site with geographic coordinates 41.50-440N, 750-790E) for 1964-1996 years.There were catastrophic earthquakes with M>7-8 (Vernyi 1887 y., M=7.5; Chilik 1889 y.,M=8.4; Kemin 1911 y.,m=8.3) at this territory. Also, more 30 strong eathquakes with M>=5 were here in 1964-1995 years including: Sarykamysh 1970, M=6.8; Galanashtup 1978, M=6.8; Baisorun 1990, M=6.3. Institute of Seismology MN-AN RK gave longtime prognosis for this territory, we waited new period seismic activization in 1996-2002.

For swarms earthquakes discrimination we elaborated algorithm Graphical Clastirisation (AGC). His core is: from regional seismic catalogue we do events matrix; all matrix elements are analysing with corresponding rules; after that results of calculations are drawing at the graphic, if taked place somewhat connections and interactions between seismic events, we see tree-structures there knots formed clasters similar with calculated by other algorithms of claster analysis. AGC has one peculiarity, he supposed crossing subsets. Such situations can to arise if living time of the subset is smaller than time of the data seclection.

WHISTLERS AS POSSIBLE PRECURSOR OF STRONG EARTHQUAKES

V.P.Kim and V.V.Hegai (IZMIRAN,Troitsk,Moscow Region,142092 Russia)

The influence of the electric field initiated by seismic activity before strong earthquakes on the upper mid-latitude ionosphere is theoreticaly studied. The nonstationary distribution of ionospheric plasma density is calculated. It is shown that near the geomagnetic force line passing through the forthcoming earthquake epicentrum the geomagnetic field-aligned inhomogeneity of plasma density is formed.The transverse size of the inhomogeneity is about 300 km.The plasma density inhomogeneity of that kind is a waveguide for very low frequensy electromagnetic waves.It will result in enhancement of whistlers appearance probability in the epicentral zone of imminent earthquake.

A POSSIBLE GENERATION MECHANISM OF ACOUSTIC-GRAVITY WAVES IN THE IONOSPHERE BEFORE STRONG EARTHQUAKES

V.P.Kim, V.V.Hegai and L.I.Nikiforova (IZMIRAN,Troitsk,Moscow Region,142092 Russia)

A generation mechanism of acoustic-gravity waves(AGW) in the ionosphere before strong earthquakes is suggested. The mechanism is based on the nonstationary local Joule heating of the ionosphere due to the pre-earthquake seismic activity initiated electric field penetrating into the ionosphere. The heating results in the excitation of the acoustic-gravity waves. The main parameters of the AGW are calculated.It is shown that the AGW amplitude is maximum at heights of 300-500 km.The wave quasiperiod is about 200 and 120 min at heights of 300 and 400 km respectively at the distance of 1000 km far from the epicentrum of forthcoming earthquake.

PREDICTION OR PRETENCE? ARE GEOPHYSICS AND EQ PREDICTION STILL CONTINENTS APART?

S P Kingsley and S R Nieder (Sheffield Centre for Earth Observation Science, University of Sheffield, Sheffield S1 3JD)

There has always been considerable interest in predicting EQs and since 1880 it has been thought that electrical effects, earthlights, groundwater changes, micro-EQ activity and changes in weather and animal behaviour might all be considered as candidate precursors. Unfortunately, very few predictions based on these and similar techniques have withstood even elementary statistical analysis and many 'predictions' turn out to be case histories that cannot be rigorously tested.

In the world of geophysics there is an increasing body of evidence to suggest that EQ mechanics arise from a process of self organised criticality and that although they may be forecastable in the long term, the short term prediction of an impending EQ may be impossible, in particular the magnitude. However, the anomalous signals measured by experimental scientists are real and not related to random processes such as noise. How are these two points of view to be reconciled? In this paper we discuss the conditions necessary for an anomaly to be associated with an EQ and how a multi-disciplinary approach can be used to improve the statistical reliability of detection, forecasting and, if possible, prediction.

STUDY OF ELECTROMAGNETIC PRECURSORS IN IONOSPHERE (WARNING PROJECT)

V.Korepanov (Lviv Centre of Institute of Space Research, Naukova str., 5-A, 290601, Lviv, Ukraine)

The possibility of existence of ionospheric precursors of seismic hazards is more and more widely accepted That is why the importance of the WARNING project, declared by the National Space Agency of Ukraine, is increased. The consultations and meetings with the European colleagues allowed to organize the international collaboration in frames of the WARNING project, which is supposed now in such composition: main satellite, the payload for which is provided mainly by Ukrainian and Russian institutions; project CESAR, prepared by the countries of Central European Initiative as passive subsatellite; project OSSI, developed in collaboration by Germany, Poland, Ukraine and possibly Japan as an active subsatellite. Each of these spacecrafts has the facilities for the study of electromagnetic phenomena in wide frequency range. The orbit and the launch time are still the subject for agreement between all parties. The payload composition of each spacecraft is presented. The main technical parameters and scientific goals of each electromagnetic package are discussed.

RADIOTOMOGRAPHY DIAGNOSTICS OF THE LITHOSPHERE-IONOSPHERE INTERACTION

V.E.Kunitsyn, E.S.Andreeva, A.V.Lyusina (Physics Faculty, Moscow University, Moscow, 119899, Russia)

There are a number of theoretical and experimental facts, demonstrating the influence of the lithosphere processes on the ionosphere. To date, there are the several models, concerning the interaction between lithosphere and ionosphere. Mechanisms of the interaction in the lithosphere-ionosphere system are discussed. But, up to now, there have been no generally accepted explanation of lithosphere processes energy transform into associated ionosphere anomalies (precursors). Therefore, the analysis of the space ionosphere structures is the very important for present-day investigations. Application of new methods of the satellite radiotomography allows to make this analysis. Probable physical mechanisms of the lithosphere influence on the electron concentration dynamics are considered. Some different variants of the space-time dynamics of ionosphere distortions are examined. Models of the space distortion structures and the computer simulation of the radiotomographic reconstructions are obtained for each variant. The results of this investigations demonstrate the possibility of the lithosphere-ionosphere interaction diagnostics with help of the analysis of the distortion space structure of the ionosphere electron density. The schemes of the experiments for this diagnostics in the seismogenic zones are suggested.

GEOMAGNETIC MONITORING FOR STUDYING MODERN GEODYNAMICS AND EARTHQUAKE PRECURSORS IN THE UKRAINIAN CARPATHIANS

V.Kuznetsova, V.Maksymchuk, Yu.Gorodysky, I.Dotsenko, I.Chobotok
Carpathian Branch of Subbotin Institute of Geophysics NASU, 3b, Naukova Str., 290601, Lviv, Ukraine

Geomagnetic investigations are carried out in the Transcarpathian Inner Trough - the moderate seismicity regions. Geomagnetic monitoring consists of different kinds of investigations: 1). Investigations of secular variation peculiarities of geomagnetic field in Europe. The SV regional anomaly zone is found in the East Europe. This zone is connected with inhomogeneities of lithosphere structure, and is correlated with spatial distribution of other geophysical parameters; 2). Investigations of deep structure peculiarities and modern geodynamics of the Carpathian polygon. The zones of geomagnetic anomalous investigations maps regions of modern geodynamic processes - deep fault, zones of active geological inhomogeneities; 3). Investigations of local anomalous effects - earthquake precursors. These investigations are based on continious F-observations at the net of 4 regime stations. During 1982-1995 21 anomalous effects 15 of which accompanied by earthquakes (i.e. more 70%) are found; 4). Investigations of temporal changes of Wiese vector and induction vectors are due to component magnetovariational observations. Temporal changes of vector parameters correspond to seismicity elevation period in the Baulcanic-Carpathian region in 1990 are determined.

DISTURBANCES OF THE LOCAL PLASMA PARAMETERS AT THE SATELLITE ORBIT ("IN SITU") BEFORE EARTHQUAKES - THE METHOD AND EXPERIMENTS

V.I. Larkina, Yu.Ya Ruzhin, Yu.V.Mineev and V.V.Afonin (IZMIRAN,Troitsk-town,Moscow,142092,RUSSIA)

There are some progress in investigations of space plasma precursors of earthquake - the magnetic conjugation of ULF preseismic emission on sattellite orbits was found in both hemisphere. It neans that some signature of precursor could be found inside the geomagnetic flux tube (shell) which connected with both conjugated ionospere regions where the ULF precursors on satellite orbits were registered.
The purpose of this paper is to present the results of the complex studies of plasmasphere parameters before and over earthquake and to compare with observation results.
There are the simultaneously registered variations:
- of intensity of a low frequency emissios fields ,
- of the density of high energy electron fluxes,
- of a environmental electron plasma temperature
as were measured on a board satellite " Intercosmos 19 " at it orbits near the future epicentre of earthquake.
Anomalous increasing of the parameter intensity was registered, when satellite was flying near (over) the earthquake epicenter 2-3 hours before strong one.Possible interpretation of the obtained results are given.

MAGNETOSPHERIC PLASMA PARAMETERS VARIATIONS OVER THE FUTURE EARTHQUAKE EPICENTRE

V.I. Larkina (IZMIRAN, Troits, Moscow Region, 142092, Russia)

The abnormal changes of a plasma parameters over the future epicentre of earthquake on a low-altitude satellite data are observed. About for days before event changes of plasma density, zone of supervision anomalous of ±3° degrees are observed. For some hours before the earthquake grows the low frequency (0,1-20 kHz) emission intensity, the changes are registered in a sight (kind) "noise belts": ±3° on latitude and ±60° on longitude. In 2-3 hours before main impact flows vigorous of particles in narrow latitude zone ±10° are marked.

The set of changes of parameters testifies in the local change of magnetosphere plasma parameters over a future earthquake epicentre and testifies about the close connection of processes occurring in the litosphere-atmosphere-ionosphere-plasmasphere-magnetosphera at preparation of the seismic event.

REMARK on the CRITERIA CHOCE for the LOW FREQUENCIES ANALYSES of SATELLITE SEISMO-PRECURSOR MONITORING

LarkinaV.I., Ruzhin Yu.Ya. (IZMIRAN, Troitsk town, Mocow Region,Russia)

There are enough work with the description of results of supervision electromagnetic seismoprecurcors on satellite data. The items of information are adduced for various parameters: fields of waves, density of a flow of vigorous particles and of density of an environmental plasma, some cases the results differ. Therefore is presented necessary before to compare results of supervision, to compare techniques (methods) search of earthquake forerunner in the various plasma parameters. For analysis we used the data of the VLF receiver aboard Intercosmos 19, which recorder the average intensity of the emission field's electrical (E) and magnetic (M) components for five filtering channels with central frequencies of 140, 450, 800, 4650 and 15000 Hz at altitude of 609-1000 km. We chose 43 cases of strong earthquakes during the satellite's active operation period (1979-1981), taking into account the following: a). Sufficiently strong events with the magnitude M > 5,5 and depth < 60 km. b). Only low-frequency earthquakes with the geomagnetic latitude of the epicentre Φ< 45° were taken into consideration. The following criteria were used to select DE-2 orbits for study]: (1). Satellite passed over the geographic latitude of an earthquake epicenter and within (20 of the epicenter's geographic longitude. (2). Satellite passed near an epicenter no more 12 hours before or 6 hours after an earthquake. (3). Earthquake body wave magnitude was more 5,0. (4). Receiver gain setting on "high" for the VLF channels. Then, DE-2 summary plot data scanned to see if the satellite was sufficiently close in time and space to an epicenter. If these criteria were met, and if the spectrometers were operating at the time. The orbit was checked against the remaining criteria for inclusion in the study. Quantitative spectral plots for all of the channels on the orbits were obtained using conubinate filter spectrometers: 20 channels between 4 Hz and 5.2 kHz. Out of a survey of over 5000 orbits, 5% orbits satisfied the selection criteria.

E-SPREAD OF NIGHT-TIME MID-LATITUDE SPORADIC LAYERS DURING SEISMIC ACTIVITY

E.V. Liperovskaya (Institute for Physics of the Earth Moscow), C.-V. Meister (Potsdam University), V.A. Liperovsky, N.E. Vasil'eva, A.S. Silina (Institute for Physics of the Earth Moscow), L.N. Roubtzov (Astrophysical Institute Dushanbe)

It is tryed to find regularities of the occurrence of diffusivity in the ionogramms of the vertical sounding station Dushanbe (measurements every 15 min. in 1988-1989) during seismoactive and quiet times. Only (≈100) earthquakes with $M \geq 4.5$ and distances of maximum 500 km from the epicentre are considered as seismic activity. It is found that diffusivity mostly appears at low fbEs ≈ 1-2 mHz. The diffusivity depends on the season and the solar activity. In 1989, at solar maximum, the diffusivity had a minimum, which is in accordance with the suggestions that acoustico(-gravity) waves forming sporadic layers are stronger damped. Mostly diffusivity seems to last 15-30 minutes. By seismic activity the occurrence time seems slightly to increase, and E-spread appears at larger fbEs. Generally one can conclude that seismic activity only very weakly influences turbulization of sporadic E-layers.

fbEs-FREQUENCY VARIATIONS WITH SCALES OF MINUTES IN MID-LATITUDE SPORADIC LAYERS

V.A. Liperovsky, S.A. Senchenkov, E.V. Liperovskaya (Institute for Physics of the Earth Moscow), C.-V. Meister (Potsdam University), L.N. Roubtzov (Astrophysical Institute Dushanbe), K.V. Popov (Institute for Physics of the Earth Moscow)

To investigate possible fluctuations of ionospheric parameters during earthquake preparation phases, at the vertical sounding station Dushanbe ionogramms were obtained every minute almost every night in Sept. and Oct. 1988, 22:30-1:30 LT, and in Oct. 18-28, 1988, 9:30-13:00 LT. It was found that sporadic E-layers strongly vary with time scales of some minutes. The intensity of spectral harmonics with periods of 2-20 minutes decreased during the seismic activities of 25.9.88-26.09.88 and 25.10.88, and after these activities it increased and got even larger than the background values. The analysis showed that the accuracy of usual vertical sounding methods are unsufficient to solve problems related to earthquake precursors. The study of the data was only possible introducing additional parameters describing the state of turbulence of the sporadic layers.

TIME SCALES OF BAY-FORMED fbEs-FREQUENCY VARIATIONS OF MID-LATITUDE SPORADIC LAYERS IN SEISMOACTIVE REGIONS

K.V. Popov, E.V. Liperovskaya (Institute for Physics of the Earth Moscow), C.-V. Meister (Potsdam University), V.A. Liperovsky, O.A. Pokhotelov (Institute for Physics of the Earth Moscow), O.A. Alimov (Astrophysical Institute Dushanbe)

Time scales of bay-formed disturbances are analysed using data of the vertical sounding station Dushanbe obtained every 15 minutes in 1985-1989. It is found that the occurrence frequencies of disturbances with time scales $\tau \lesssim 0.5$ h and $\tau \approx 0.75$-1 h are almost equal. But they are 2-3 times larger than the values for $\tau \approx 1.25$-1.5 h, $\tau \approx 1.75$-2 h, $\tau \approx 2.25$-3 h. The number of disturbances decreased during years of larger solar activity. But concerning the seasonal dependence, maximum numbers were obtained for summer time. Comparing seismoactive and quiet nights, it is shown that only two days before an earthquake the number of disturbances with $\tau \approx 2$-3 h has a tendency to increase (1.1-1.7 times), even at magnitudes $M \gtrsim 4.5$. The number of the disturbances with other time-scales seems to be unchanged.

ELECTROMAGNETIC PHENOMENA CAUSED BY THE KAYRAKUM EARTHQUAKE IN 1985

V.A. Liperovsky, K.V. Popov, E.V. Liperovskaya (Inst. for Earth Phys. Moscow), C.-V. Meister (PotsdamUniv.), M. Parrot (LPCE /CNRS Orléans), O.A. Alimov (Astrophys. Inst. Dushanbe)

Usually studying electromagnetic effects of seismic activity one analyses the time dependence of one parameter for a number of earthquakes. We perform a study for a complex of ionospheric parameters and the electromagnetic field at the earths' surface for only one event. Ionogramms of the vertical sounding station Dushanbe situated about 220 km from the epicenter of the Kayrakkum earthquake on 13.10.85 were investigated. The analysis of the variations of the ionospheric parameters shows that seismoionospheric processes started two days before the event. The processes seemed to cause ionospheric heating, and to increase the variability of sporadic layers as well as to decrease their average density. Besides large-scale ionospheric turbulization was activated and strengthened E-spread phenomena, lasting also one day after the event. The number of large-scale perturbations of the F2-layer with periods of two hours grew. Ionospheric disturbances, modulations of the electromagnetic noise intensity and local geomagnetic field disturbances had the same time scales and occurrence regularities. This result could help to understand lithospheric-ionospheric links before earthquakes.

ELECTROMAGNETIC AND ACOUSTIC EMISSION ACCOMPANYING MICROCRACKING PROCESSES IN CRYSTALLINE MATERIALS

C. Mavromatou, and V.Hadjicontis (Solid Earth Physics Institute, University of Athens, Panepistimiopolis, 157 84, Zografos, Athens, Creece)

D.Zilpimiani (Georgian Academy of Sciences, 1 Rukhadze str., Tbilisi, 38009, Georgian Republic)

During the uniaxial compression of rock samples, or of pure ionic crystals, and after the stress has exceeded a critical value, electromagnetic (EME) and acoustic emissions (AE) are observed. The intensity of the emissions is recorded and it is found to increase drastically as the sample approaches failure, whereas silent intervals are also observed. The recording of individual electric, magnetic and acoustic pulses, which accompany the crack opening, is accomplished by a transient recorder with high sampling rate (25×10^6 samples/sec). The study of these experimental results may support a plausible model for the origin of the observed electromagnetic disturbances.

SUDDEN INCREASE IN THE DAILY STANDARD DEVIATION OF THE GEOELECTRIC POTENTIAL DIFFERENCE BETWEEN SHORT-SPACED AND MULTI-CHANNELLED ELECTRODES OBSERVED IN THE SEISMICALLY ACTIVE WAKAYAMA,JAPAN

J.Miyakoshi,I.Shiozaki(Institute of Earth Sciences,Tottori University, Koyama-cho,Tottori,680Japan) M.Nakamura,N.Seto(Earthquake Research Institute,University of Tokyo)

Geoelectric observations are being made in Wakayama City,Japan,in the hope of detecting precursors to large earthquakes.Shallow earthquake activity in and around Wakayama City has always been anomalously high. Five earthquakes of M>4.0 occurred in and around the Kii Peninsula including the Wakayama City area in 1994 and 1995. Also, the Kobe Earthquake of M=7.2 occurred about 50 km in distance from Wakayama. Since electric noises mainly produced by electric trains are dominant during the daytime in the Wakayama City area, we monitor the SDm(n) m=1~9, the standard deviation of the geoelectric potential differences measured every 10 minutes on 9 channels during the night (01h30m 03h00m) on short spaced(20 meters at most)paired electrodes. SDm(n) is usually about 0.5 mV, however, it increases more than 1 mV or sometimes to more than 5 mV abruptly before earthquakes of M>4.0 occurred in and around the Kii Peninsula which is located close to the subduction zone of the Phillippine Sea Plate. However, sudden increase of SDm(n) was not observed before the Kobe Earthquake.

THE NECESSITY OF BROADBAND STUDIES FOR RESEARCH INTO PRECURSORY PHENOMENA

S R Nieder and S P Kingsley (Sheffield Centre for Earth Observation Science, University of Sheffield, Sheffield S1 3JD)

This paper explores the problems posed by bandwidth limitation in SEM precursor studies and goes on to demonstrate that broadband experiments are vital for obtaining data that is useful for understanding these kind of geophysical phenomena. Systems that rely on narrowband detectors with threshold crossing counters may have a place in measuring levels of impulsive EM activity associated with seismogenic processes. This technique has been widely used at least partly due to the small amounts of data it produces. There are serious limitations as to what such experiments may be able to tell us about the processes which generate the SEM phenomena. Broadband experiments that directly record the EM signal produce vast quantities of data, the data rates being calculable from consideration of the bandwidth and the application of the Nyquist criterion. However, in spite of this problem, such a sampled system will produce useful information to improve the understanding of the geophysical processes being studied. EQ preparation processes of both periodic and aperiodic nature will be discernible from such data sets, as will the identification of other non-seismogenic noise sources. Furthermore models that have been hypothesised can be tested against this kind of experimental data as well as providing an incentive for future experiments.

MATHEMATICAL MODEL OF A POSSIBLE MECHANISM OF ELECTRO-MAGNETIC AND TEMPERATURE EARTHQUAKE PRECURSORS.

O.B. Novik (Moscow State Geol. Prosp. Acad., 117246, POB 51, Moscow, Russia)
I.B. Mikhaylowskaya (Moscow State University, Facit. of Math., 119899, Russia)
S.V. Ershov (Keldysh Inst. for Appl. Math., 125047, Moscow, Russia)

Low-resistivity structures(LRS: 0.1Sm/m; sizes~10x20, depth~20, km) were discovered by MTS in many seismic regions. The generation and propagation of electromagnetic (em) and temperature (t) field disturbances (precursors?) are computed as a result of the e-em-t field interaction in a model 2D lithosphere zone with LRSs, destabilised by elastic (e) displacements (ampl.~1cm, freq.~1Hz ,duration ~ 5s) appeared in upper mantle. The equations of e-, em- and t-field have been included, together with the non-linear field interaction operators, in the system of PDEs of the mathematical model. Some of the characteristics of the precursor evolution are as follows: e- and t- waves are moving to the earth's surface together; the em-signal arrives 2s before them (path ~20km); the h-amplitude is up to 1nT in LRSs,deformed by e-waves, and up to 30pt at the surface or above it; the em-field is decreasing rapidly out of LRSs because of a multipole structure of h-disturbances in them;LRSs were found to be main converters of the energy of seismic activation into em-signals; t-signals in sediments are of order of 0.02K; the surface time series of em- and t-signals have an ULF spectrum similar to one of a deep (40km) seismic excitation and the amplitude increasing together with one of an excitation.Using colours for field zones of different intensity, the distinctive computer images of different phases of seismogenic dynamic of the interacting fields have been obtained (interpretation of signals).

ON THE USE OF TEC DATA TO SURVEY SEISMO-ELECTROMAGNETIC EFFECTS

M. Parrot, LPCE/CNRS, 3A, Avenue de la Recherche Scientifique, 45071 ORLEANS Cedex 02, France

Many evidences of ionospheric perturbations after strong earthquakes have been reported in the past. The perturbations occur just after the shock and are due to acoustic gravity waves. Further more, it has been shown that ionospheric perturbations could also occur a few days before earthquake. Although this phenomena is not well understood, it could be related to a redistribution of the electric charges at the surface of the Earth and then in the upper atmosphere. The purpose of this paper is to investigate the TEC (Total Electron Content) variations measured by the DORIS system on board the low-altitude satellite TOPEX-POSEIDON in relation with seismic activity. TOPEX-POSEIDON is dedicated to space oceanography and have altimetric systems for measuring the altitude of the satellite. Measurement of fluctuations in the integrated electron density or TEC between the satellite and the ground is used to remove the ionospheric influences in order to obtain a better estimation of the altitude. The DORIS system is composed by a network of orbit-determination beacons distributed around the world and a radio receiver onboard the satellite which measures the Doppler shifts in two frequencies. We used the ionospheric correction for the altitude measurement from the AVISO CD-Roms. The earthquakes have been chosen with a magnitude $M_s > 5.0$ and a distance between epicentre and ground track < 300 km. We considered satellite data during 48 hours before the shock. In a first time, studies of particular events are presented. These perturbations could be increases as well as decreases of TEC. They are studied as function of different parameters (magnitude, local time, location) and compared with natural variation of TEC.

SPACECRAFT OBSERVATIONS OF ELECTROMAGNETIC RADIATION ASSOCIATED WITH EARTHQUAKES

A. N. Panteleev (Institut de Physique du Globe de Paris, 4 place Jussieu, 75252 Paris 05, France)
J. Achache (Bureau de Recherches Géologiques et Minières, 3 avenue C.Guillemin, B.P. 6009, 45060 Orléans 02, France)

We study ELF/VLF electromagnetic signal recorded by the satellite AUREOL-3 and compare it with a catalogue of seismic events of $M_s \geq 5$. Although the data are very scarce (only 1% of time around earthquakes is covered), we show that a statistically significant portion (about a half) of 40 satellite records acquired within a time interval of several hours and within 10° of longitude from earthquakes appears to carry seismically-associated signal. As reported in previous studies (e.g. Parrot, 1994), the amplitude of the signal is shown to decrease with the distance to the earthquake source. The signal tends to be clearer in periods of weak geomagnetic activity, at lower frequencies (140 Hz still available) and particularly in the vertical component of the magnetic induction. The signal may be produced by different types of earthquakes, including the deep (440 km) ones. More continuous observations are needed to undertake a well-conditioned multi-parameter correlation analysis of this type of earthquake-related signal.

EARTHQUAKE SYNCHRONIZATIONS AS A POTENTIAL TOOL FOR PREDICTING EARTHQUAKES

G.A. Papadopoulos (Institute of Geodynamics , National Observatory, 11810 Athens, Greece)

Space-time earthquake synchronizations have been considered in the past as a potential tool for predicting earthquakes. In this sense, an earthquake EQA occurring in a seismic zone A triggers an EQB in a zone B. Should such a dynamic interaction is systematic between A and B, then each EQA is a potential precursor of a corresponding EQB. To interprete earthquake synchronizations a linear stress accumulation in zone B is assumed. After an EQA occurrence the stress accumulation in B is being non-linear because of additional stress released by EQB occurrence. Successful short-term predictions of the 15-6-95 (M6.0) and 1-2-96 (M5.6) earthquakes in western Greece from space-time synchronizations are reported.

THE EARTHQUAKE (M6.4) OF 10 OCTOBER 1996 IN THE CYPREAN ARC: A PRECURSOR OF A LARGE SHOCK IN THE HELLENIC ARC?

G.A. Papadopoulos (Institute of Geodynamics, National Observatory, 11810 Athens, Greece)

The Cyprean Seismic Arc (CSA) is much less active with respect to the Hellenic Seismic Arc (HSA).In the period 1896-1996 there were 43 strong shocks (Ms 6.0) recorded in HSA while only 4 events were recorded in CSA. However, 3 out of 4 CSA events were followed by HSA strong events within a maximum time interval of 4 months. Given that earthquake synchronizations are rather common in the Mediterranean Sea, a hypothesis has been made that strong CSA earthquakes constitute precursors of strong HSA events. A 5th strong CSA shock (Ms= 6.4) occurred on 10th October 1996. Should the hypothesis is valid then a strong (Ms 6.0) HSA event is expected to occur until 10 February 1997 with a probability of 0.75. The probability for predicting by chance this event is only 0.12 and therefore the probability gain benefited from the earthquake synchronization observations goes up to 6.25.

THE SEISMIC ACTIVITY IN ALBANIA FOR THE PERIOD 1977-1993

V.Peçi (Seismological Institute, Tirana, Albania)
P. Shuteriqi (Seismological Institute, Tirana, Albania)

Based on the instrumental data we are going to present the development of the seismic activity during the last 15-th years, for the whole territory of Albania and as well as the seismic activity for the different active zones.
The number N of the events for the last four years is getting smaller. The variations of the b-coefficient before some moderate earthquakes $M_L \geq 5.0$ are significant and the values of this coefficient for the last period are decrease too.
In this paper we are going to present the maps of the distributions of the seismic activity for the different periods and area.
According to the study of the: N-numbers of the events; a and b coefficients-the seismic regime parameters; logE - seismic energy released and the maps of the distributions of the seismic activity we can see that there is a low seismicity which is developing in the last four five years for the territory of Albania.

Seismicity (Ms ≥ 7) in the rupture zones of very great (Mw ≥ 8.5) shallow thrust earthquakes, in the decades before and after the main shocks.

O J Pérez (Simón Bolívar University, Department of Earth Sciences, Sartenejas, Edo. Miranda, Apdo. Postal 89.000, Caracas 108, Venezuela)

We analyze the occurrence of large (Ms≥7) seismic events in the rupture zones of six very great (Mw ≥ 8.5) shallow (h<70 km) thrust earthquakes in the circum Pacific, in the decades preceeding and following the main shocks. The study is made after constructing a revised instrumental seismicity catalog (1900-1996) for the world by removing a series of heterogeneities in terms of completeness of earthquake reporting and magnitude determination. Contrary to what expected, in all but one case (1964 Alaska, Mw~9.2) shallow thrust events with Ms=7 to 8 have occurred in the rupture zones, actually very closed to the main epicenters of the very great ruptures (VGR) analyzed, in the decades following them. For instance, shocks with Ms~8 in 1959, and Ms~7.8 in 1975, occurred near the main epicenters of the 1952 (Mw~9) Kamchatka and 1960 (Mw~9.5) Chile earthquakes, respectively. Contrary to what forecasted by the seismic gap hipothesis, this "long-term aftershock activity" implies that places where VGR nucleate have larger than usual seismic hazard, in the decades following them. Long-term foreshock (Ms≥7) activity also occurs at these nucleation places in the decades prior to the main shocks, whereas most of the remaining portions of the forthcoming VGR do not experience such activity. Since the events analyzed occurred in segments of plate boundaries that either were or could have been identified as seismic gaps for shocks with Mw > 8; and since a long quiet period for events with Ms≥7 in a gap does not appear to indicate an increased seismic potential along it (Kagan and Jackson, *J. Geophys. Res.*, 96, 21,419, 1991), we conclude that gaps showing relatively recent large (Ms~7+) events are more likely to generate great shocks than those not showing any significant seismicity for many decades.

GEORESISTIVITY ANISOTROPY PRECURSORS TO EARTHQUAKES IN CHINA

F. Y. Qian (Institute of Geophysics, SSB, Beijing 100081, China)
Y. L. Zhao (Institute of Geophysics, SSB, Beijing 100081, China)

There are often anisotropic georesistivity variations before earthquakes. In-situ experiments have indicated that, even the soil stratum is horizontally isotropic, the variation of its resistivity is still anisotropic when it is stressed and the variation is related to the state of stress (compression or shear) and the direction of the major principal compression. Based upon these results, it would be possible to determine the parameters of stress field. The paper has given the methods for guantitatively calculting the parameters, α, λ, $(\rho_1\rho_3)^{1/3}$ and $(\rho_2\rho_3)^{1/2}$, of georesistivity anisotropy for two cases; one is from data measured along three lines that make arbitrary angles with one another; the other is from data measured along only two mutually perpendicular lines and an additional measurement of the transversal effective resistivity. Two case histories have been processed: one is that before and after the M6.1 Datong earthquake on October 19, 1989, the anomalous rise of NE-trending georesistivity and obnormal fall of NW-trending georesistivity were observed at two stations in the epicentral region, which mainly caused by shear acting on the medium and thus there was a smaller normal stress on the fault surface so that the fault was likely to slide but the earthquake was only of moderate magnitude; The other is that it is inferred from anisotropic decreases in georesistivity observed along two mutually perpendicalar lines that before the M7.8 Tongshan earthquake of 1976, the crust was compressed. The fault was locked by a greater normal stress so that the earthquake was of great magnitude.

MODELLING OF EXCITATION OF EMW BY LITHOSPHERE SOURCES AND THEIR PROPAGATION THROUGH IONOSPHERE.

Yu.G. Rapoport, I. Kremenetsky and V.V.Grimalsky (Kiev University, Physics Faculty, Astronomy and Space Physics Dpt., Glushkov pr. 6, Kiev 252022 UKRAINE)

The amplitudes of electromagnetic waves (EMW) including Alfven waves at frequencies $f = 1 - 20Hz$ which appear above the epicenters of future earthquakes at altitudes $500 - 900km$ (as it is planned in Ukrainian satellite mission Warning) are calculated. The propagation of EMW in nonuniform waveguide (lithosphere-atmosphere-ionosphere- magnetosphere, 10 plane layers at all) is considered. The outer layers (half-spaces) are lithosphere and magnetosphere. The lithosphere currents (the sources of radiation) are given at the lower waveguide boundary. It is assumed that lithosphere current is localized in the vicinity of epicenter of earthquake. Detailed calculations are made for the bypassing of satellite over the Carpathian region. The oblique magnetic field is taken into account. It is supposed that as a result of microcurrents correlation on the last stage of earthquake preparation effective mucrocurrent is excited with approximate size $\sim 100km$. The sourses of different physical nature including moving charged dislocation with 2D space distribution have been supposed. For different initial spectrums of current source the spectrums of ionospheric distarbences are obtained. It is shown that: (1) Displacement of the maxima of magnetic field of the EMW at the altitude $600km$ is about $100km$ for angle $\theta = 20°$; (2) For frequency $F = 100Hz$ the maxima is smoothed.

SEISMO-IONOSPHERIC PRECURSORS AND IONOSPHERIC VARIABILITY

S.A. Pulinets, V.Kh. Depuev, V.V. Khegai and A.D. Legen'ka (IZMIRAN, Troitsk, Moscow Region, 142092, Russia)

One of the most strong objections against the usefulness of seismo-ionospheric precursors is that they look like usual variations of ionospheric parameters named day-to-day ionospheric variability, and sometimes are less than variations during strong disturbances (storms and substorms). The latest studies show that they have unique physical mechanism, and therefore, observed seismo-ionospheric variations could be revealed in any conditions, even during strong disturbances. The only problem is that one should analyze several parameters simultaneously, i.e. plasma density, height density distribution, ion composition, local time dependence, etc. This statement will be supported by comparison of physical mechanisms of seismo-ionospheric variations development with development of magnetic storm within the ionosphere. Under the same negative variations in plasma density the increase of effective ion mass takes place during the storm development, contrary, diminishing of the effective ion mass is observed within the F-layer for seismo-ionospheric precursors. The negative phase of the magnetic storm co-rotates from the night to the day side, while the negative variations connected with the earthquake preparing is observed only before the sunrise, and is positive during morning hours. The storm variations have global nature, while seismo-ionospheric precursors are observed only near future epicenter. The new visualization technique used recently for ionospheric data analysis permit reveal the sources of ionospheric variability.

TEST-SITES FOR EARTHQUAKE PREDICTION EXPERIMETS WITHIN THE COLLI ALBANI R EGION

F. Quattrocchi and M. Calcara (Istituto Nazionale di Geofisica (ING), Via di Vigna Murata 605, 00143, Rome, Italy)

In this paper geochemical time - series gathered by discrete and continuous groundwater monitoring, carried out throughout the Colli Albani region, selectin g some deep gas discharge sites, are discussed. In particular we stressed the resu lts obtained at the continuous geochemical monitoring station (GMS I- BAR site) designed by ING for seismic surveillance. Strict correlations between seismic events and fluid geochemical anomalies are been discovered (Eh, Rn, CO2, NH3, etc...). Phase separation processes at depth between reducing - acidic vola tile vapour phase, and a hypersaline brine, characteristic of a medium - entthalpy geothermal reservoir, like hyphotesised for the Colli Albani area is the hyphotesized explanation of the ob served correlations. Moreover in the paper an historical list (since 1700 up today) of correlations between gaseous discharges and geochemical anomalies over the Colli Albani area, with respect local and remote seismic events is reported: hints for future geochemical surveillance sound test-site within the Colli Albani region are suggested. State of art about a new prototype of Geochemical Monitoring System (GMS II) is pointed out, stressing the multiparametric strategy for earthquake prediction experiments: the TIV and Etna sites was selected for the installation in the frame of two EC recently financed programs (Geochemical Seismic Zonation and Automatic Geochemical Monitoring of Volcanoes, Contracts ENV4-CT96-0291 and ENV4-CT96-0289 respectively).

MAGNETIC CONJUGATION OF APPEARANCE REGIONS OF THE SEISMOIONOSPHERIC PRECURSORS

Yu. Ruzhin, V.I.Larkina and Anna Depueva (IZMIRAN, Troitsk-town , Moscow Region, 142092, RUSSIA)

The magnetically aligned conductivity provides hard electrodynamic coupling of conjugated ionosphere regions. Therefore ionosphere disturbances over the earthquake preparation region (or precurcors) have to form their definite images in magnetically conjugated region of the ionosphere. Satellites INTERCOSMOS-18 and ALOUETTE data were analyzed from this point of view. Conjugated earthquakes precursors were found in very low frequency (VLF) emission and F2 peak plasma parameters.

F2-precursors appeares some days before the earthquake, manifest themeselves as an anomaly like Appleton anomaly if epicenter of future earthquake is situated near magnetic equator. Estimation of electric field magnitude necessary to generate observing event was made. It was shown that the electric field less than one mV/m must be generated in the ionosphere.

VLF precursors which appears some hours before the earthquake are localized close to magnetic shell corresponding to future earthquake epicenter and have a belt-like structure (longitude aligned more than some tens thousands kilometers) in both hemispheres. VLF precursors are followed by energetic particles (W>40 keV) precipitation.

EARTHQUAKE FORERUNNERS AS SPACE PLASMA AND WAVE ANOMALIES

Yu.Ruzhin and Anna Depueva (IZMIRAN, Troitsk, Moscow Region, 142092, RUSSIA)

Ionosphere is a good indicator of ionosphere-lithosphere coupling processes. Related to lithosphere and crust processes ionospheric variations found not only after strong earthquakes but some days before the main shock. The latter may be considered as earthquake precursors. Among a variety of known ionospheric anomalies caused by a forthcoming earthquake there are some main anomalies, which to our mind could be taken as a basic for satellite earthquake prediction system development. A comprehensive analysis of diverse seismoionospheric precursors was carried out which made it possible to select three main precursor types at ionosphere distinguishing from each other by place and time of appearance: 1) Lower ionosphere boundary reaction - some days before (up to two weeks); 2) Anomalous plasma structures formation in full volume of the ionosphere - two-tree days before; 3) VLF radiation generation in the ionosphere registered on satellite board at 500-800 km altitude range - some hours before.
On the basis of common to all precursors main parameters - appearance time (hours-some days) and minimum earthquake magnitude for which ionosphere response exist (M>4,5) it was shown that only modification of atmospheric electricity may be the most appropriate reason of earthquake precursors appearance in the ionosphere among other reasons. It is shown that common property of all seismoionospheric precursors is the fact, that horizontal dimensions of precursor observations exist within radius R(M) of epicenter of earthquake originally defined by Dobrovolsky theory for ground precursors measurement. In other words preparation zone dimension in the ionosphere are maintained even in magnetically conjugate region equal to ground zone dimension. It is additional argument in favor of atmospheric electricity as a possible reason of seismoionospheric precursors appearance.

VARIATIONS OF SEISMICITY IN SOUTHERN KAMCHATKA

V.Saltykov (Kamchatka Seismological Department of Geophysical Survey, 9, Piip Av., Petropavlovsk-Kamchatsky, 683006, Russia)

Southern Kamchatka (Russia) is one of the most probable places of strong earthquake with M>7.75 in Kurilo- Kamchatka arc. The aim of this work is detection of seismic anomalies in this region such as seismic quiescence, ring seismicity, etc.
The analysis of seismicity of this region is carried out by using data of the Kamchatka regional catalogues (1962-1996). A level of representative registration is equal to M=2. Previously the catalogues were cleared from aftershocks and swarms of earthquakes. The temporal dependencies of seismic parameters are received for zones of the various sizes.
Seismic quiescence is observed in Avachinsky Gulf from the middle of 80-s. The size of this anomaly is equal to 150 km × 60 km. It is possible to assume, that seismic quiescence began to be formed from the center of Avachinsky Gulf and is distributed around it. The increase of the seismic activity near Avachinsky Gulf can be connected to occurrence of ring seismicity. The location of earthquakes with M>5 during last five years confirms this assumption: they restrict the selected zone of seismic quiescence.

THE NATURE OF ELECTROMAGNETIC NOISE PRECEEDING EARTHQUAKES

V.V. Surkov (Moscow Engineering Physics Institute, Kashirskoye sh., 31, 115409, Moscow, Russia)

The physical nature of large-amplitude increases in the electromagnetic (EM) ULF signals, observed 3-4 hours before the Loma Prieta and Spitak earthquakes, are discussed. Theoretical models based on the cracks charge movement have some problems, related with necessity of large surface charge density and of similar orientation of all electric micro-dipoles. New physical mechanism for the explanation of the emergence of EM precursors has been proposed. It is based on the effect arising from the geomagnetic field perturbations caused by acoustic impulses from micro-cracks in the conductive crust. It is shown that before these acoustic impulses reach the observation point, the magnetic micro-fields of all cracks are of the same sign regardless of their spatial orientation. Because all effective magnetic micro- dipoles are opposite to the geomagnetic field the diamagnetic effect arises. Summing up all the micro-fields result in the effect which could be considered as a collective magnetic precursor. According to estimates the resulting EM fields may reach the values of 3-4 nT and 0.005 mV/m. Under certain conditions the cracks, which are incoherent acoustic sources, may be coherent sources of low-frequency EM field. This circumstance can explain the fact that the preceding earthquakes EM activity is observed in the absence of a seismic one.

TYPICAL VARIATIONS OF THE HIGH-FREQUENCY SEISMIC NOISE CONNECTED TO PREPARATION AND REALIZATION OF STRONG EARTHQUAKES

V.Saltykov, V.Sinitsyn, V.Chebrov, E.Gordeev (Kamchatka Seismological Department of Geophysical Survey, Petropavlovsk-Kamchatsky, 683006, Russia)

Response of high-frequency seismic noise (HFSN, frequency - first tens of Hz, amplitudes - 1.0E-9 - 1.0E-12 m) to Earth's tides is investigated. The tidal wave O_1 (T=25.82 h) is one from strongest tidal waves. This wave will play a role of the reference action upon medium. Observation of the HFSN was conducted in one point on Kamchatka during four years. The envelope of the quasiharmonic noise signal was used for analysis. There is shown, that the HFSN component, having period of the wave O_1, has a phase varying in time. These variations are connected with changes of stress condition of medium. The seismicity is considered in radius of 250 km from the point of registration. The stabilization of a phase on some level was observed before 10 earthquakes with magnitude M>6. The duration of this stabilization is equal to some months. It is possible, that the value of the stable phase level is connected to position of the earthquake epicenter. After earthquakes the HFSN phase sharply varies. The average jump of the phase is equal to π.
The authors propose opportunity of use the HFSN monitoring for intermediate-term prediction of strong earthquakes. The last strong Kamchatkan earthquake (21-Jun-96, M=7.1) was predicted before 3 days. It was successful prediction of earthquake's time, location and magnitude.

A COMPARISON BETWEEN "SLOW EARTHQUAKES" AND REGISTERED SHORT-TERM LOW-FREQUENCY PRECURSOR.

E.V.Sasorova (State Oceanographic Institute, Kropotkinsky per 6, Moscow,119838, Russia)
B.W.Levin (P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences, Krasikova 23, Moscow,117218, Russia)

It is discussed the similarity of the characteristic properties of the short-term low-frequency seismic precursor detected by data processing of seismograms (Levin B, Sasorova E, Volcanology and Seismology, 1994, 4, 128-133,Annales Geophysicae, EGS, 1994, Part 1, p.202) and "slow earthquakes" (P.F.Ihmle, T.H.Jordan, Science, vol. 266, 2 December 1994, p. 1547-1551). The earthquake preparation scenario is introduced. It uses the geomechanics block-hierarhical approach for the explanation of the both events correlation.

HYDROGEOSEISMOLOGICAL PRECURSORS OF EARTHQUAKES

A.N.Sultankhodjaev, Sh.S.Yusupov (Institute of Seismology, Uzbekistan Academy of Sciences)

Spatial and temporal changes of the hydrogeo-seismological (HGS) parameters are determined for the territory of Uzbekistan depending on the geological structure and seismotectonic features of points of observations. The HGS precursors are caused by both the inhomogeneity of the geological medium and sources mechanism, physical, chemical and thermodynamic properties of the hydrochemical system. Informativity of the HGS parameters for every point of observation are determined experimentaly and are confirmed by the quantitative estimation of statistical effectiveness and informativity. Regional features of subsoil waters isotope composition distribution and its forming are determined by experimental study on the territory of Central Asia. Isotopes of carbon, oxygen, hydrogen and rare gases are the criterion of HGS anolalies forming and can be used as the criterion of precursors.

THE SEARCH FOR GEOCHEMICAL PRECURSORS OF EARTHQUAKES IN FRENCH PYRENEES : a methodology for high-resolution, high-frequency automatic monitoring and for active faults mapping

J.P. Toutain, M. Munoz (OMP, UMR CNRS 5563, Toulouse, Fr), J.C. Baubron, J.L. Pinaud (BRGM, 40060 Orléans, Fr)

Pyrenees is a 400 km-long intraplate belt showing E-W oriented domains separated by major accidents. Seismic activity is characterized by some destructive earthquakes (up to M = 7.0 in 1428) and by frequent quakes of magnitudes < 6.0.

Two pluriparametric monitoring stations were set up in 1996 on thermal springs located close to seismic epicenters. Bubble gases (^{222}Rn, He, O_2), soil ^{222}Rn, dissolved ions (Cl, Ca, K, Mg), physical parameters of water (pH, Eh, temperature) and external parameters (air temperature, atmospheric pressure, precipitations) are continuously recorded with 15 to 90 mn steps. Data are stored on a datalogger and transmitted to the laboratory via modem.

Chemistry of bottled groundwater was also investigated after a M=5.7 earthquake that occured in western pyrénées in February 1996. The sampling station was situated about 18 km from the epicenter. A clear chlorine anomaly (about 40 % above background values) was noted starting about 5 days before the quake and lasting 10 to 13 days. This precursory chemical change is attributed to a preseismic strain-induced mixing of chemically different aquifers. These results confirm the potentiality of mineral springs as optimum sites for the search of chemical precursors of earthquake.

ON THE PROBLEM OF IDENTIFICATION AND DISCRIMINATION OF ELECTRICAL EARTHQUAKE PRECURSORS

A.Tzanis (Dept. of Geophysics & Geothermy, Univ. of Athens, Greece).
S. Gruszow (Laboratoire de Geomagnetisme et Paleomagnetisme, Institut de Physique du Globe de Paris, Paris, France).

The possibility of electrical precursors to earthquakes has long been appreciated, but to date there still exists neither a solid theory to describe the expected precursory waveforms, nor proven techniques to identify and discriminate precursors from noise. In addressing the latter problem, the only published approach and criteria involve simultaneous observations on elaborate arrays of short and long dipoles (e.g. Varotsos & Lazaridou, Tectonophysics, 188, 321-347, 1991). We demonstrate that these techniques are ineffective and can easily be deceived by local noise into identifying it as a distant signal, leading to false alarms. Furthermore, we discuss that some problems in identifying local, anthropogenic noise can be addressed, (1) with simultaneous measurement in a number of simple, distributed stations and, (2) with measurement of the magnetic field. Emphasis in given to the latter, on the basis of Magnetometric Resistivity method. In support of these concepts, we present an example for the case of the 13/5/1995 M6.6 Kozani event, claimed to have been predicted by the VAN group. We show that there have been no physical grounds for a prediction.

ELECTRIC CURRENT GENERATION ASSOCIATED WITH DEFORMATION RATE OF A SOLID: PRESEISMIC AND COSEISMIC SIGNALS.

F. Vallianatos, (Technological Educational Inst. of Crete, Chania Branch, Crete, Greece.
A. Tzanis, (Department of Geophysics & Geothermy, Univ. of Athens, Athens, Greece)

We present a model for the generation of electric current in rocks under stress, involving the strain rate, which is influenced by the motion of charge bearing dislocations. The relationship between current density and strain rate is demonstrated. On the basis of laboratory data, we estimate the deformation rate necessary to generate an electric signal observable at distances far enough from the source, as to qualify it as an electric earthquake precursor. Using this mechanism and the geometrical characteristics of such a type of source (plane or line), we simulate the propagation of the electric signal and its 'received' characteristics as a function of the source-receiver separation. We conclude that the expected signal waveforms at long distances from such a kind of source are very similar to a class of signals (long period, bay like waveforms), independently observed prior to earthquakes by several investigators.

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SEISMOGENIC RADIOEMISSIONS AS PRECURSORS TO EARTHQUAKES IN GREECE.

F. Vallianatos (Technological Educational Institute of Crete, Chania, Crete,Greece & Geodynamic Institute, National Observatory of Athens)
K. Nomikos (Technological Educational Institute of Athens, Greece) and
E. Vakakis (Technological Educational Institute of Crete,Chania, Crete, Greece).

A multipoint network was constructed along Crete island (Greece) for earthquake prediction using seismogenic electromagnetic emissions. The network consists of four observation points. Each observation point has (a) loop antennas tuned to 3 and 10 kHz (LF). The final stage of the antennas is an RMS to DC converter. Thus the output of the receiver is a DC voltage that is proportional to the power spectrum density Φ_H of the magnetic field that excites the antenna, (b) $\lambda/2$ dipoles to observe variations in 41 and 53 MHz (HF). In this stage the DC output is proportional to the electric field which appears on the $\lambda/2$ antenna. In the present contribution recordings of the electromagnetic anomalies that precede to earthquakes during the last three years are presented. The experimental results indicate the presence of radioemissions, associated to shallow and intermediate depth earthquakes in the vicinity of Crete island. It is concluded that the electromagnetic variations appears to follow an invariant time pattern (i.e. LF variations - HF variations - Earthquake event). Furthermore, a statistical analysis of the predicted events, based on an empirical approach introduced by Rikitake, is given.

A NEW TELEMETRIC NETWORK IN GREECE FOR THE INVESTIGATION OF THE SEISMOELECTRIC EFFECT.

P. Varotsos, E. Skordas, K. Nomikos and V. Hadjicondis (Solid Earth Physics Institute, University of Athens, Athens, Greece)

Currently VAN group is installing, in Greece, a telemetric network for the simultaneous continuous measurements of the motion of the ground and of the electric field variations. At seven of the existing VAN stations an additional system is installed that simultaneous measures one seismic (short period z-component) and two electric channels (N-S, E-W). The digital acquisition equipment for this purpose, the seismometer (ZM500), and the data acquisition and restoring software is supplied by LDG (France). The 50 Hz frequency of the electric channels is filtered before digitisation. Data are coded with 24 bits and the three channels are sampled at 50 Hz. Data frames of 10s duration are transmitted from the acquisition site to the station where are multiplexed with VAN data. With a modem next to the multiplexer all data are transferred to the central station in Athens via a leased telephone line. At the central station a PC network is installed for the data acquisition and analysis. Data can be viewed directly as coming from each station or any time later as are compressed and stored in the PCs. Two optical disks exist also for data archiving and one tape streamer for backup. The main objective of the above configuration is to study if there is an electric signal during or shortly before an earthquake.
This work is supported by the project EPET II-388

A COMMENT ON THE CRITERIA FOR DISCRIMINATING SEISMIC ELECTRIC SIGNALS FROM NOISE

P. Varotsos, N. Bogris, K. Eftaxias, M. Lazaridou, A. Abdulla and P. Kapiris. (Solid Earth Physics Institute, University of Athens, Greece)

By investigating VAN data of 28.5 months, Nagao, Uyeshima and Uyeda (*Geophys. Res. Lett., 23,* 1441-1444, 1996), checked the correctness of the four VAN criteria for discriminating Seismic Electric Signals (SES) from noise, and found results in basic agreement with those published by VAN. One of these criteria states that the quantity $\Delta V/L$ should be constant when comparing (neighbouring) short dipoles in a given direction; it was clarified by Varotsos and Lazaridou (*Tectonophysics 188,* 321-347, 1991) that this criterion is applicable only when the area is *homogeneous.* Furthermore, Varotsos et al. (*Jishin, 17,* 18-26, 1994; in *The Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals,* ed. Sir. J. Lighthill, Word Scientific Publishing Co., Singapore, 29-76, 1996) emphasized that when investigating (neighbouring) sites at which the directions of the electric field polarization are different, the constancy of $\Delta V/L$ should *not* be retained. Gruszow et al. (*Geophys. Res. Lett., 23,* 2025-2029, 1996) claim that the criterion "$\Delta V/L$=const." is violated for the SES that preceded the 6.6 earthquake at Grevena-Kozani. MT measurements show that Gruszow et al. compared sites which exhibit different directions of electric field polarization.

MAGNETIC FIELD VARIATIONS ACCOMPANYING SEISMIC ELECTRIC SIGNALS (SES)

P. Varotsos, N. Sarlis M. Lazaridou, N. Bogris and J. Makris (Solid Earth Physics Institute, University of Athens, Greece)

VAN repeatedly published that SESs are not accompanied by *observable* variations of the *horizontal* magnetic field (B_H). This, of course, does not mean that SES are not accompanied by magnetic field variations (the existence of which are obligatory from Maxwell equations), but that they are very small [cf. drastically smaller than those, which produce MT electric field variations having comparable amplitude (and period) to the SES] and hence are not readily detectable; in other words, there is a question of detectability *only* of the magnetic field variation for the usual cases of M 5.0-5.5 at $r \approx 100$km. On the other hand, for EQs with M 6.5-7.0, a value of $B_z \sim 1$nT (i.e., mainly on the *vertical* component) is consistent with the model of SES transmission suggested by Varotsos et al. (*Tectonophysics 224,* 1-37, 1993). This was observed before the 6.6 Kozani-Grevena EQ; claims (e.g., Gruszow et al. [1996]) that this observation could be attributed to a nearby artificial source contradict: (1) the theory, because, in such a case [cf. point horizontal current dipole IL, $f=10^{-3}$-10^{-3}Hz, $\sigma=\sigma(z)$], B_z cannot exceed B_H [as $B_z=(\mu_o IL/4\pi r^2)\sin\vartheta$, while $B_H=(\mu_o IL/4\pi r^2)$], (2) the experiments, at Ioannina, because they result in $B_z \leq B_H$, for such artificial sources.

POSSIBLE CORRELATION INCREASE OF NEUTRON FLUX FROM EARTH SURFACE AND EARTHQUAKE AT FULLMOON AND NEWMOON

N.N.Volodichev, B.M.Kuzhevskij, O.Yu.Nechaev, M.I.Panasyuk, A.N.Podorolsky, P.I.Shavrin (D.V.Skobel'tsin Institute of Nuclear Physics, Moscow State University, 119899, Moscow, Russia)

The phenomenon of neutron flux increase from Earths surface during newmoon and fullmoon, discoverd by us, connected with maximum influence force of gravitation from Moon and Sun on the Earth and change of gradient sign of gravity at this time. These causes can also be responsible for an earthquake occurence. Analysis of data on earthquakes with magnitude >4 at 1964-1992 years shows, that in a number of cases a prolonged series of earthquakes takes place in the days of newmoon and fullmoon or in near-by days. Therefore, it cannot be excluded, that neutron flux increases from the Earth surface may be used as earthquake precursor.

THE FLUX VARIATIONS OF HIGH ENERGY CHARGED PARTICLES IN MAGNETOSPHERE OF EARTH AS A NEW EARTHQUAKE PRECURSOR.

S.A. Voronov (Mosow Physics Engineering Institute, 31 Kashirskoe shosse, Moscow, 115409, Russia)
A.M. Galper and S.V. Koldashov (Moscow Physics Engineering Institute, 31 Kashirskoe shosse, Moscow, 115409, Russia)

Basing on 10 years investigations of high energy charged particles fluxes dynamics in magnetosphere by means of instruments installed on spacecraft it was found the correlation between the variations of particle intensities and earthquakes as temporal and spatial as well. It displays as increase of counting rate of charged particles several hours before active phase of earthquakes with magnitudes more then 4 (Richter scale) Such a phenomenon is explained by resonance interaction of VLF electromagnetic emission of seismic origin with charged particles trapped in radiation belt above an epicenter and following drift of disturbance along the longitude in the same L-shell as epicenter has. The fact of spatial correlation of epicenter position and place of registration of intensity variation gives the possibility to obtain the coordinates of future earthquake some hours before its beginning with accuracy up to 100 km in real time and so use this precursor in practice.

RECENT PROGRESS IN EVALUATING THE PRECURSORY SEISMIC QUIESCENCE HYPOTHESIS

S. Wiemer and M. Wyss (Geophysical Institure, Univ of Alaska Fairbanks Fairbanks, AK, 99775-7320, USA)

This presentation will focus on some of the recent progress made in studying seismic quiescence. We are now able to perform a detailed spatial and temporal mapping of seismicity rate changes in map view or cross-section. By using 'Alarm Cubes', all false alarms can be identified, making it possible to establish the ratio of precursory anomalies, missed events, and false alarms. Using these and other improved analysis tools, we have described three current quiescence anomalies in the vicinity of Tokyo (Japan). Based on the standard seismic quiescence hypothesis it is not unreasonable to expect M6.5 mainshocks in these locations. However, we have formulated the new hypothesis that crustal volumes with anomalously high b-values may not be capable of major earthquakes. All three anomalously quiet volumes near Tokyo show higher than average b-values, and may therefore not be able to generate main shocks. Cases of crustal volumes that showed precursory quiescence and anomalously low b-values include the 1990 M6 Izu-Oshima (Japan) and the Morgan Hill (M6.0) 1984 main shocks. If we find more evidence of this nature we may want to modify the precursory seismic quiescence hypothesis to apply only to crustal volumes with low b-values. This may significantly reduce the false alarm rate which we currently estimate to be 50the precursory seismic quiescence hypothesis will be a hypothesis testing scheme implemented in real time.

MODERN GEODYNAMICS OF THE NORTHEN AND SOUTHERN BOUNDARIES OF THE EURO-ASIAN PLATE BY SEISMIC DATA

F.N.Yudakhin, T.Y.Belenovich. Institut of Ecological Problems in the North, Urals Division of Russian Academy of Scs.Arkhangelsk, Russia

The analysis of seismisity and focal mechanisms specifies a number of general features in behaviour of the southern and nothern boundaries of the Euro-Asian lithosphere plate. Both boundaries by cross faults are divided into a number of large lincs, each of which is characterized feature of focal mechanism (upthrow, fault, displacement, shift and etc.).The trajectories of the earthquake sources migration are distinguished within the limits of each link, that is stipulated by stress field peculiarities. All soueces of strong earthquake M> 6.0 are on the units crossing plate boundaries by cross faults, where occurs the change of focal mechanism types. It is characteristically that strong earthquake occur in the zones of compression, while in the zones of spreading they are not observed, but in the latest frequent earthquake recurrence is marked.

"GEONOM" TECHNOLOGIES: NEW TREND IN GEOLOGICAL PROGNOSTICATION

F.N.Yudakhin, S.P.Alexandrov, M.G.Gubaydullin
(Institute of Ecological Problems of the North of the Urals Branch of RAS, JSC'Northern Mining & Geological Company 'Terra', JSC'Arkhangelskgeoldobycha')

Unique technologies of computer-aided investigation of mapped features of geological and geophysical maps 'GEONOM' are presented. They maintain performance of efficient geological prognostication /of mineral resources deposits, seismically hazardous zones etc./ under the conditions when other methods of maps examination are ineffective. It is can be provided with the use of unique geometrical methods of localization and analysis of geological fields with mapped features of complex structures. These methods for investigation of laws of spatial distribution of the Earth's crust structural and tectonic features provide efficent prognostication of geological objects. 'GEONOM' technologies were successfully used for prognostication of diamonds, gold, hydrocarbons deposits in some regions of the world and of seismic activity in Kyrgyzstan. The surveys were performed in scales of 1:25 000 to 1:5 000 000. They are the most efficient for preliminary sorting of anomalies prospective for mineral resources discovery and for prediction of deposits within the areas where customary prospecting works have been actually completed, however, new deposits occurence can be expected.

TRANSMISSIBILITY PRECURSORS AND STICK-SLIP RELEVANT TO THE TANGSHAN EATHQUAKE

Y. L. Zhao(Institute of Geophysics, SSB, Beijing 100081, China)
F. Y. Qian(Institute of Geophysics, SSB, Beijing 100081, China)

Transmissibility is characteristic of the connectivity of cracks and/or pores in the rocks, which mainly includes permeability and resistivity. The decreases in both resistivity and water levels beginning approximately 4 years priol to the M7. 8 Tangshan earthquake were observed over a large region. So the resistivity change cannot be the result of changing saturation even if the apparent resistivity paradax is taken account of. According to one of Brace's experimental results that permeability, k, and electrical resistivity, ρ_s, are closely related by $k=c\rho_s^{-1.5}$, we have $\Delta k/k=-1.5\Delta\rho_s/\rho_s$. For fluid flow, q, of equilibrium in the time scale of many geological processes, it is appropriate to neglect changes of q in the reservoir and from Darcy's law, $q=(k/\mu)P$, where P is pressure difference, which is very similar to Ohm's law, $I=V/R$, we obtain $\Delta P/P=-\Delta k/k$. In terms of the two equalities, changes in water levels was calculated from changes in resistivity and the results show that the predicted values are in good agreement with the observed. Since the rock-soil layers are partially saturated, the observed resistivity decreases are interpreted by result of in-situ experiments that the resistivity decreses when compressed, which is due to increasing the connectivity. The decreases in both resistivity and water level are due to increasing confining pressure. Taking account of experimental results that high normal stress favours stick-slip motion and that the magnitude of the stress drops depended on confining pressure, stick-slip may well be the more relevant for the great Tangshan earthquake.

SE7 Global seismology

Convener: Kind, R.
Co-Conveners: Jacob, A.W.B.; Weber, M.

EXPERIMENTAL STUDY OF ELASTIC AND ELECTRIC EARTHQUAKE PRECURSOS

Maria Zamora, Isabelle Grandidier (Institut de Physique du Globe, URA 734, 4 place Jussieu, 75252 Paris, France) and
Laurence Jouniaux (Ecole Normale Superieure, 24, rue Lhomond, 75231 Paris, France)

With the aim of detecting earthquake precursors, parallelepipedic samples of limestone (with porosities ranging from 30% to 40%) saturated with Na Cl solution (1 S/m conductivity) have been deformed until rupture, in non-drained conditions. During uniaxial deformation P, SH and SV wave velocities and attenuations, and electrical conductivity, were measured in three perpendicular directions. Cracks and fractures (generally oriented parallel to the stress direction) are generated that produce: 1) Decreasing of V_P, V_{SV} and V_{SH} in the two directions of the plane perpendicular to the applied stress direction. V_{SH} drops more quickly than V_{SV}, causing a birefringence of S-waves that grows with fracturation. 2) Increasing of attenuation, particulary that of SH-waves. 3) Decreasing of the V_P/V_{SV} ratio, with approximately constant V_P/V_{SH} ratio. 4) Emergence of anisotropy of electrical conductivity.

ANALYSIS OF LATE ARRIVAL SEISMIC PHASES USING LONG PERIOD ARRAY PROCESSING

Y. Cansi (Laboratoire de Détection et Géophysique, Commissariat à l'Energie Atomique, BP 12, 91680 Bruyères-le-Châtel, France)
E. A. Okal (Northwestern University, Department of Geological Sciences, Evanston, Illinois 60201, USA)

Long period seismograms recorded on the French permanent national network of the Laboratoire de Détection et de Géophysique are used to study late arrivals in the coda of strong deep earthquakes. An array processing tool (the PMCC metho d) and a classi cal 3-component analysis are applied.
The detection criterion of the PMCC method is based on a search of correlated si gnals independantly of any amplitude consideration. It is particularly suitable for de tection of little stable arrivals in an incoherent coda.
Each detected phase is characterised by its propagation and spectral parameters (phase velocity, azimuth, amplitude and frequency band); these parameters are co mpared with 3 components results.

CHARACTERISATION OF RECENT SEISMIC PATTERNS IN CALABRIA, SOUTHERN ITALY.

Castiglia, G., Ceravolo, E., Ferrucci, F., Guerra, I., Moretti, A., Sottile, M.

Between 1993-1996 the seismic activity in the Calabria peninsula was marked by occurrence of sparse sequences of either shallow (crustal depth) or deep earthquakes of generally moderate Magnitude. Microearthquakes arranged in typical mainshock-aftershock sequences, the strongest being that of May 1996 near Acri (northeastern Calabria, Mmax=3D4.6), or in form of long lasting microseismic swarms, as that recorded at Mormanno (northern Calabria : 1,000 microearthquakes with M< 2.5 between August-November 1993). Observation of some such sequences by means of a portable array of three-component stations, in addition to the permanent seismic network, allows to characterise the seismic source and the properties of the medium at several locations, and to highlight the role of some presently active structures in the extremely complex tectonic framework that characterises both the northern and the southern Calabria.

STACKING PROCEDURE OF SEISMIC REFLECTIONS FROM THE CMB AND D" LAYER: PRELIMINARY RESULTS

Nuno Afonso Dias[1], L.A. Mendes-Victor[1], Rainer Kind[2], COMBO Group[3]
[1]CGUL/ICTE, Rua Escola Politécnica 58, 1250 Lisboa, Portugal;
email:flvictor@skull.cc.fc.ul.pt);
[2]GeoForschungsZentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany;
[3]DIAS, School of Cosmic Physics, 5 Merrion Square, Dublin, Ireland.

A set of seismic events of magnitudes above 6.0, selected from the PDE monthly catalogs, were processed in order to analyze the inhomogenous lowermost mantle (the D" layer) and the core-mantle boundary. These events were recorded by the vertical component of broadband seismic stations belonging to the German Regional Seismic Network, the Gräfenberg-Array and the GEOFON Network. The aiming was to establish a good regional coverage of the CMB region.
The purpose of the stacking applied to this data was to enhance the signal corresponding to the PdP phase, reflection on the D" and precursor to the PcP, using the P phase as reference. In order to improve the stacked record section, the distance-time wavefield was transformed into the slowness-time domain. For P and PcP the method increases the coherence of this phases, but as it concerns the PdP it is necessary to make the analysis within narrow azimuthal bands, due to the fact that the irregularity of this layer seems to affect its travel times.

SEISMIC CONSTRAINTS ON MODELS OF THE MANTLE

C H Estabrook and R Kind (GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany)

We use several constraints to develop a velocity model for the 660-km discontinuity ('660'). The amplitude of the underside P-reflection coefficient must be reduced while simultaneously maintaining large underside S reflections and PS conversions. We search all possible P-wave velocity (V_P), S-wave velocity (V_S) and density (ρ) combinations which satisfy these criteria. V_S and ρ are bounded by the IASP91 (Kennett and Engdahl, 1991) and AK135 (Kennett et al., 1995), respectively. In order to isolate exactly what elastic constants are changing, we recast the jump at 660 to that of the Lamé parameters μ, λ. The 2% V_P change is the same as having no change in λ and the seismic parameter Φ. Thus a continuous λ and Φ at the 660 explain the missing underside P reflections and lead to a V_P jump of only 2% while the V_S and ρ remain nearly unchanged with respect to previous global models. This model changes only slightly the amplitude of the PKPPKP (P'P') underside reflection from the 660, thus reinforcing its validity. The main characteristic of the boundary between the upper and lower mantle is then a jump in μ and ρ. The model de-emphasizes the role of λ with regard to the shear modulus μ and constrains the mineralogical composition across the discontinuity.

A DIGITAL PROCEDURE TO ELABORATE ACCELEROGRAMS SUPPLIED BY AN ACTUAL ITALIAN SEISMIC NETWORK: GEOPHYSICAL AND GEOTECHNICAL ANALYSES

G.FINZI-CONTINI DIC, Via S.Marta 3, Florence, Italy; Florence Univ.
S. GORI DIC, Via S.Marta 3, Florence, Italy; Florence Univ.

Ground Motion (GM) during earthquakes represent the starting point for many geophysical / geotechnical analyses. Spectra of the GM signals constitute the basis in order to study seismic responses of structures. The strong motion instrumental records cannot be used to describe the GM owing to Environmental Noise (EN) superimposed to actual seismograms. The numerical approach allows one to both correct the EN and reduce the Noise-to-Signal Ratio fraction. The process errors can be classified as follows: errors due to film warping in the drive mechanism during the registration; random digitisation errors; aliasing and so on. The necessary process in order to correct the GM acceleration data is classifiable into two sections : the first one consists of the choice of the filters frequencies; the second one consists of the selection of the filter type. A quantitative correction is proposed by this work: one assumes an algorithm based on a simple hypothesis. Substantially, we assume that the EN (in its casualness) is proportionally representative of the spectral response in the dominion bounded by the filter frequencies. The correction is realised by the PITSA software; the adopted process concerns the GM instrumental records supplied by an actual Italian accelerograph network. Our results are carefully examined to control their reliability.

New large scale *P*-velocity models of the mantle under Europe and central Asia

V. Geyko, T. Tsvetkova, N. Sannikova, L. Livanova and K. Geyko. Institute of Geophysics of National Academy of Sciences of Ukraine Kiev, Ukraine av. Palladin 32, 252680 Kiev-142, Ukraine

New large scale 3-D *P*-velocity models of the mantle beneath Europe (EUR-*PG*) and central Asia (CAS-*PG*) to 850 km depth has been defined. The initial data have been first-arrival times of *P*-waves from major seismic events for 1966-1990. New method of seismic tomography proposed by V. Geyko has been used for inversion of the data. The errors of velocity recovering do not exceed ±0.015 km/s. The following solid properties of the mantle have been explained. (1) The Earth's mantle is subdivided into the two shells by the global boundary situated at 550-680 km depth. Below it, beginning from 750-800 km depth, the velocity distribution approaches the radials-symmetric one and invariant ones even to major tectonic structures. In this context this surface treated as the tectonosphere bottom. (2) Age and type of the tectonic structures are reflected in the tectonosphere. (3) The intermediate boundary of tectonosphere situated at 390-450 km depth and the astenosphere is not global. The former is peculiar to the ancient and formed structures and later to those actively living now. (4) The manifestation of the tectonic elements in the mantle may be not only characterized by the absolute velocity values but also by the whole totality of the velocity model features. (5) The lateral inhomogeneity of the mantle is mainly determinate by the thermal regime heterogeneity of the Earth.

CODA Q_C EVALUATION USING LOCAL SEISMIC EVENTS IN THE FRIULI AREA

A. Govoni, P.L. Bragato and G. Bressan (Osservatorio Geofisico Sperimentale, Centro Ricerche Sismologiche, Udine, Italy)

The coda Q_c has been estimated in the Friuli area (NE Italy) using several local events recorded by the Friuli-Venezia-Giulia seismic network from 1988 to 1993. For this analysis, based on Aki & Chouet (1975) model, a new code has been developed with the aim to achieve automatic selection of traces to be processed, high numerical computation efficiency to process large data sets and control on several parameters affecting coda determination among which the most important is the length of the time window (lapse time) used in coda regression. Results show a linear dependence of Q_c from frequency $Q_c = Q_0 f$, where Q_0 is of order 80 for a lapse time of 40 s. Q_0 values do depend on lapse time and this fact, reported by several authors, can not be explained by the Aki model.
Great attention has been devoted to the possibility of resolving the Q_0 structure on regional scale at low lapse times in the limit of the spatial resolution of the method.

MANTLE TOMOGRAPHY USING SURFACE WAVE OVERTONE DATA AND BODY-WAVE AND MANTLE-WAVE WAVEFORMS

H.J. van Heijst and J.H. Woodhouse (Department of Earth Sciences, Oxford University, Parks Road, Oxford, UK)

A new mode branch stripping technique, enables us to measure the dispersion properties for several surface wave mode branches independently from single seismograms. The direct measurement of overtone dispersion has a number of advantages over a waveform modelling approach since it allows signals of low amplitude in the waveform to be extracted and to be given higher weight in inversion. The resulting phase velocity distributions can be interpreted as, possibly nonlinear, functionals of the local earth structure.
The new method has now been applied to approximately 50,000 waveforms, rendering between 30,000 reliable measurements for the fundamental mode to about 4000 for the 4th overtone. We present high resolution (up to l=20) phase velocity maps for both Love and Rayleigh waves and compare them to maps predicted by existing mantle models.
The resolving power of the dataset is extremely good, as shown from modelling of global three dimensional structure. Good formal resolution is achieved all through the upper mantle and fast, possibly slab related features are found around the transition zone. Finally, we combine the dispersion dataset with body-wave and mantle-wave waveform data. We investigate whether the two datasets agree and to which extent the discrepancy between Love and Rayleigh waves can be resolved introducing anisotropy.

AN ANALYTIC SPHERICALLY SYMMETRIC *P*- AND *S*- WAVE VELOCITY MODEL

Y. Lana-Renault (Geophysics - Department of Theoretical Physics, University of Zaragoza, Pedro Cerbuna 12, 50009 Zaragoza, Spain)

The problem of the Earth's interior constitution is considered under the perspective of an analytic spherically symmetric P- and S- wave velocity model. This model is derived from a guess function for the distribution of the density in the Earth's interior, $\rho(r) = \rho_0 + a_0 \cdot \log(\frac{R_0}{r})$, which depends only on the radial distance to each layer, and where a_0 is a parameter and (ρ_0, R_0) are the density and radius for the upper boundary of each layer. The analytical function for the velocity allows us to adjust the arrival times of the different seismic phases with a high precision, around the 99%, yielding a valid reference model since satisfies the most important classes of seismological observations. In this sense, we compare our results with the successive PREM, IASP91 and SP6 Earth models. In addition, several calculations for the moment of inertia of Earth are performed, obtaining a precision upper than 99.5%.

TELESEISMIC BODY WAVES RAY TRACING BASED ON GRAPH THEORY

R. Montelli, E. Boschi and G.B. Cimini (Istituto Nazionale di Geofisica, Rome, Italy)

We present a method for computing raypaths and travel times of teleseismic phases based on advanced graph theory (Moser, 1991). The method overcomes some difficulties that arise in the use of standard ray shooting and bending methods assuring the globally minimum traveltime between two fixed points even in very complex structures. Graph theory systematically searches for the shortest path connecting the source with a specific point, in a network of nodes representing the velocity model. Every node is connected to a finite number of nodes in its direct neighbourhood (forward star). The algorithm we propose allows to examine in detail the effect that strong lateral eterogeneities, like those expected in subduction zones and in strongly contrasting low-velocity bodies such as magma chambers, have on both trajectories and travel time of teleseismic phases. We show also examples in which further bending of the graph path is performed to achieve an increased accuracy of the final ray path (Moser *et al.*, 1992).

The structure of the seismic upper mantle discontinuities at 410 and 660 km depth in subduction zones

X. Yuan, R. Kind, G. Bock (GeoForschungsZentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany), S. Beck (Department of Geosciences, University of Arizona, Tucson, USA)

We study P- to - S converted phases at the 410 and 660 km discontinuities in the Japanese and Andean subduction zones. The data used are from permanent broadband stations and from a temporary deployment of broadband stations in Bolivia (BANJO). At both subduction zones we see no indication of converted waves from 410 km depth at stations directly above the penetration of the slab trough the 410 km discontinuity. The 660 km discontinuity is always visible. However this discontinuity is downward deflected underneath China to the west of region where the slab hits the discontinuity. The depth is normal to the east of that region. Our observation can be explained by the complete destruction of the 410 km discontinuity and a depression of the 660 km discontinuity by the impact of the moving slab.

Continuous Weak-damped Oscillations Cased by Earthquakes on the Active Continental Margin Bounderies as Generation Sources of Tsunami Waves

Medvedev N.I., Lab. of Geomechaniks, Institute of Marine Geology & Geophysics, Yuzhno-Sakhalinsk, 693002, Russia

Solving the problem on propagation of elastic waves in the layer (Lamba's problem) gives the dispersion relation. The analysis of this relation shows that together with actual values of the wave vector which depends on frequency there exist also imaginary values which correspond to heterogeneous waves damping exponentially along the axis of propagation. These oscillation stable in time and space have definite frequences of propagating waves.

Solving the dispersion equation for the system: elastic layer on elastic hemispace having flexible contact between them which in fact corresponds to break in the continuity, also gives as actual and imaginary values of wave vector, in this case the latters correspond to the oscillations which have damping coefficient depending on condition on the boundery between the layer and hemispace. The theoretical analysis indicates that these oscillations can continue for the first dozens of minutes if the parameters correspond to those of the real medium. Such oscillations which occur in the limited regions of the Earth were discovered experimentally too.

The weak-damping oscillations of great amplitude can be an excitation source of tsunami waves in the continous lithospheric ledge of the active continental margin.

VARIABILITY OF INTERMEDIATE TO LONG PERIOD SURFACE WAVES AS RECORDED BY DENSE BROADBAND ARRAYS

H. A. Pedersen*, N. Cotte*, S. Gregersen**, R. Kind***, J. Ni****
*LGIT, Université Joseph Fourier, BP 53x, F-38041 Grenoble Cedex, France; ** Kort og Matrikelstyrelsen, København, Denmark; ***GeoforschungsZentrum Potsdam, Germany; ****New Mexico State University, USA.

Due to sparse station coverage, the local variability of intermediate to long period surface waves has been somewhat neglected in the past. With new data from temporary broadband arrays, it is observed that the propagation characteristics of fundamental mode surface waves can change significantly over short distances, i.e. under much less than a wavelength. As an example, surface waves recorded by the INDEPTH II array in southern Tibet (across the Tsangpo Suture) change significantly along the array. The phase velocities change and strong amplitude anomalies are observed. Numerical simulations show that these amplitude anomalies can be explained by the presence of strong lateral heterogeneities in the middle to lower crust, with an almost vertical termination of a low velocity layer. Another example is from TOR0, a temporary array of 24 broadband stations located along a profile crossing the Tornquist Zone in southern Scandinavia. The close station spacing used in TOR0 makes it possible to follow significant changes in waveform almost continuously along the array.

SPATIALSEISMIC CHARACTERISTICS OF CHINA

C.Y. Qin, E.E. Papadimitriou, B.C. Papazachos and G.F.Karakaisis (Laboratory of Geophysics, University of Thessaloniki, GR-54006, Thessaloniki, GREECE)

Based on all available historic and instrumental information for earthquakes in China, the following three complete and homogeneous samples of earthquakes have been defined: 1800-1995 MS(8.0, 1900-1995 MS(6.0, 1950-1995 MS(5.0. These three samples have been used to study the geographical distribution of seismicity in China. For this reason, the parameter b of the Gudenberg cumulative frequency relation of the magnitude was first calculated for several parts of the area. It was found that the b values increase from northwest China (b=0.81) to Taiwan (b=1.03). By using these b values, the geographical distribution of the parameter a of the Gudenberg relation was determined. In order to get reliable parameters for the above zones, statistic test was adopted at significance level 99.5%. Moreover, the mean return periods for every 10,000Km2 for different magnitude cutoffs are calculated. The minimum values of them are found in Taiwan region which coincide quite well with the seismicity distribution.

OBSERVATION AND EXPLANATION OF ASYMMETRICALLY REFLECTED PP/SS PRECURSORS

M. Schimmel and H. Paulssen (Department of Theoretical Geophysics, Institute of Earth Sciences, Utrecht University, P.O. Box 80.021, 3508 TA Utrecht, The Netherlands.)

Since more than 30 years asymmetrically reflected PP precursors are observed at epicentral distances ranging between 80° and 120°. Slowness and travel time constrain their ray paths to have bounce points at about 15° to 30° distance from the receiver or source. Their existence has been explained by the presence of heterogeneities in the lithosphere, the presence of dipping interfaces, or upper mantle reverberations and conversions. We show asymmetrically reflected PP and SS precursors observed for different regions and different event-station azimuths. It is shown that these arrivals cannot be explained by the existing excitation mechanisms. A new mechanism is required. We propose a mechanism which can excite asymmetrically reflected precursors in a realistic one-dimensional (1-D) Earth, i.e. without the need of lateral heterogeneities, although the presence of heterogeneities can additionally strengthen the excitation of precursors. They are not really stationary phases and are therefore probably overlooked up to now. We discuss the excitation mechanism using Huygen's principle and are able to explain the observations. Synthetics are calculated, but have a more qualitative character due to the use of ray geometrical amplitudes. These PP and SS precursors seem to be a fundamental contributor to the P- and S-wave coda.

PRECISE SLOWNESS VECTOR MEASUREMENTS USING THE GERMAN REGIONAL SEISMIC NETWORK (GRSN) AS A LARGE APERTURE ARRAY

K. Stammler and F. Krueger (Seismologisches Zentralobservatorium Gräfenberg, Krankenhausstr. 1-3, 91054 Erlangen, Germany)

The German Regional Seismic Network (GRSN) consists of 15 permanent stations in Germany, equipped with 3-component STS-2 broadband sensors. The aperture of the network is approximately 400 x 500 km but it still shows array features.
We used the network for source location with P-waves applying a crosscorrelation method and a plane wave approximation. In most regions the mean deviation of the observed slownesses from the IASP91 model is very small for strong earthquakes leading to precise locations. Even for distances larger than 80 deg, where the bottom part of the P-waves comes close to the core, the observed slownesses can be explained quite well by theoretical seismograms computed for the IASP91 model. As an exception the path to South America shows slowness deviations abut 0.15 seg/deg which would be explained by velocity variations in the deep mantle of about 0.2-0.3 km/sec.
GRSN data are continuously archived since about 5 years in 20 Hz and 1 Hz data streams. Data requests are welcome. For information mail to Klaus Stammler (`klaus@szgrf.uni-erlangen.de`).

SE8 Real time earthquake surveillance and hazard assessment

Convener: Husebye, E.S.
Co-Conveners: Console, R.; Papaioannu, C.A.

S-WAVES TIMING USING SHORT PERIOD VERTICAL SEISMOMETER

L. Badiali, A. Basili and F.M. Mele (Istituto Nazionale di Geofisica, Rome, Italy)

We present a search algorithm of secondary phases applied to vertical short period, local and regional seismic signals. This algorithm is already implemented at the National Italian Seismic Network (RSNC), as an aid to the analysts in their job of picking and relocation. The RSNC is prevalently constituted by vertical S13 seismometers. With this kind of instruments the signal amplitue is seldom sufficient by itself to clearly detect the beginning of a secondary phase. Often the analist tends to attribute the onset of the S wave to the most evident variation of frequency he can see in the record. We propose a way to automate and improve this process. The algorithm searches for the maximum of a characteristic function defined comparing the signal power spectra of two ovelapped moving windows. The procedure can be easily applied in a real time acquisition system.

A REAL-TIME MONITORING AND ANALYSIS SYSTEM

G. Calderoni, B. De Simoni, F.M. De Simoni, L. Merucci (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143 Rome, Italy)

The Argo Satellite Seismic Network is a system for the real-time monitoring, collection, visualization and analysis of seismic and geophysical low-frequency data. The seismic data flow coming from 12 remote stations connected through the satellite link to the data processing centre of the Istituto Nazionale di Geofisica of Rome, is automatically analyzed by specific software. The analysis allows to operate a real-time automatic extraction of the seismic signal from the station noise and to determine the local magnitude and duration magnitude. The technique used is very simple and reliable. The efficiency of the procedure used will be discussed.

FUZZY INFORMATION RETRIEVAL AND ANALYSIS IN AN ARCHIVE OF SEISMIC WAVEFORMS

C. Chiaruttini (DINMA, University of Trieste, I-34127 Trieste, Italy)

An effective exploitation of large archives of seismic waveforms requires the use of automatic tools for signal retrieval and analysis. Because of the large variability in seismic waveforms, qualitative analysis tools are often a useful complement to quantitative ones. We present the design and implementation of *Fuzzy_E20*, a system for waveform-based information retrieval and analysis. Before storing in the system database, signals are analysed and decomposed into a combination of three primitives: onset, body and coda. The primitives are described by parameters like: amplitude, frequency, duration, peak value, onset and coda slopes. Information retrieval is supported by a specifically designed query language, allowing the qualitative definition of a vast set of waveforms with user-friendly linguistic expressions. *Fuzzy_E20* includes a user defined knowledge-base of *morphotypes*, i.e., typical waveforms, still described with the query language. The system can operate in three modes:
1) Direct user query;
2) Automatic classification of signals into morphotype classes;
3) Maintenance of an explanatory database, which can be used to explore signal properties not explicitly stated in the morphotype definitions.
A friendly interface assists the user in composing syntactically correct queries and morphotype definitions. Retrieved signals are presented with a decreasing degree of match, avoiding unnatural crisp thresholds. *Fuzzy_E20* has been applied to the analysis of seismograms recorded on the Stromboli volcano, Italy.

REAL-TIME GEOPHYSICAL OBSERVATION:ITS APPLICATION TO EARTHQUAKE WARNINGS

R. Console (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143 Rome, Italy)

One of the possible uses of real-time geophysical observation is its employ in an earthquake warning system. Provided that an anomaly which can be considered a possible earthquake precursor is observed, the problem arises whether it should be used in practice or not. Just in economical terms, one should be able to estimate the costs of the actions to be undertaken by the community after having issued an alarm, and the reduction of the expected losses caused by an earthquake, if a correct alarm is issued in proper time. This is not a geophysical problem, involving economic, social and political sciences, but its solution requires reliable geophysical information. The use of every kind of precursors, or system making joint use of different kinds of precursors, implies the preliminary quantitative definition of the threshold values to be exceeded for declaring an alarm. It is also necessary to define both the spatial and the temporal extension of the alarm, expired which the alarm is to be regarded as failed. The systematic observation carried out over a suitable period of time will allow the statistical assessment of both the success rate and the false alarm rate. It is obvious that, the lower the threshold values defining the anomalies and the larger the space-time extension of the alarm, the larger is the number of events which will be predicted, but the more costly will be the use of the alarm system to the community. So, there is a clear trade-off between the number of successful alarms and the number of false alarms: a kind of problem which decision makers must be aware of, and that can be dealt with only with an exhaustive knowledge of the statistical properties of the precursors.

SPECTRAL CLASSIFICATION METHODS IN MONITORING OF SMALL LOCAL EVENTS BY ISRAEL SEISMIC NETWORK.

Y. Gitterman, V. Pinsky and A. Shapira, Seismology Division, Geophysical Institute of Israel

The identification of seismic events as small as mb=2.0 at regional distances is of critical importance to achieving the goal of the CTBT monitoring. In this study we explore the performance of network-oriented spectral discriminants using waveforms of 73 earthquakes and 139 quarry and underwater blasts with magnitudes 1.0-3.0 in Israel and Jordan, recorded by short-period stations at distances up to 300 km. The single-station seismic energy spectral ratio the low (1-6 Hz) and high (6-11 Hz) frequency bands shows an overlap between explosions and earthquakes. After averaging over a subnetwork, the resolving power is enhanced and the two classes of events are separated. We estimated also r.m.s. spectral amplitudes in five sequential equal frequency windows within the 1-11 Hz band and applied multiparametric automatic classification procedures to a subnetwork averages. A lay-one-out test showed low rate of mistakes for the procedures. A newly developed multi-station discriminant is based on spectral modulation, associated with ripple-firing in quarry blasts and with the bubbling effect in underwater explosions: a distinct azimuth-invariant coherency of spectral shapes for different stations in the frequency range (1-12 Hz). The coherency is measured by semblance statistics commonly used in seismic prospecting for the phase correlation in time domain. After modification, the statistics, being applied to the network spectra, provided event separation. All mentioned procedures are based on smoothed (0.5 Hz window) FFT spectra of the whole signal, without picking out separate wave phases; they are robust to the accuracy of onset time estimation, and thus are well suited for automatic event identification.

THE HYBRID SEISMIC EVENTS DURING SEISMIC CRISIS OF KORJAKSKI VOLCANO: ITS APPLICATION FOR ERUPTION FORECASTING

E.I.Gordeev and S.L.Senjukov (KEMSD, Geophysical Service of RAS, a.Pijp. 9,683006 Petropavlovsk-Kamchatsky, Russia)

Korjakski volcano is the classic stratovolcano with altitude 3456 m in vicinity of the principal city of Kamchatka, Petropavlovsk-Kamchatsky with population around 300 thousands. The time of the last eruption was estimated nearly 3500 years ago. In the beginning of March, 1994 was started the seismicity just under volcano with position of the events no deeper than 10 kilometers. The total number of events were about 100 which continued till end of May, 1994. Among the normal volcano-tectonic earthquakes were found very specific events with prerecorded signals which had different duration just before onset of P-waves. The location of the sources of this signal shown very good fitting with main shocks. The duration changed from a few seconds to twenty. The detail analysis of the wave forms on the different stations, the spectral composition and hipocenters distribution provided good explanation of the originality of these signals as magma activity. The dependence of the event's parameters on the time gave good possibility for prediction of the volcano activity.

AUTOMATED ANALYSIS OF REGIONAL EVENTS AT THE GERMAN NDC

G. Hartmann (Federal Institute for Geoscience and Natural Resources, Hannover, D-30631 Germany)
N. Gestermann (Federal Institute for Geoscience and Natural Resources, Hannover, D-30631 Germany)

Within the framework of the international data exchange experiment GSETT3 the German seismological data center at BGR developed automatic procedures for detecting and locating local and regional seismic events. Parameters of detected seismic signals are obtained running a Murdock-Hutt-Detector at each digital broadband station of the German Regional Seismic Network (GRSN) including the GERESS array. This data form the basis on which seismic events are tentatively defined by associating the detection times from at least three stations. Event epicenters are estimated by a grid search algorithm. To avoid misassociations of the arrivals and mislocations of the events several consistency checks are applied with respect to station distribution, magnitude and time residuals. These procedures are supplemented by new features, such as automatic magnitude calculation and phase association algorithms based on 3-component polarization analysis. Events are analyzed interactively and the results are automatically stored into a seismological database. This data can be accessed by interactive tools or by AutoDRM in a standard bulletin format (GSE2.0).
It can be demonstrated that the combination of these methods improves the results of automatic epicenter determination.

FAST AND ACCURATE EPICENTER DETERMINATIONS USING ARRIVAL TIMES OF PG AND LG ENVELOPE PHASES

E.S. Husebye and B.O. Ruud (Institute of Solid Earth Physics, University of Bergen, Allégaten 41, N-5007 Bergen, Norway)
A.M. Dainty (Phillips Laboratory, Earth Science Division, 29 Randolph Str., Hanscom AFB, MA 01731-3010, USA)

Local event recordings are complex and hence difficult to analyze in an automated manner. Filtering such records in the 2–4 or 3–6 Hz passband and then taking the envelope transform in combination with a lowpass filter we obtain smooth, low-frequency records with excellent SNRs. The dominant envelope features are the Lg wavelet (3.5 km/sec) and the Pg wavelet (6.0 km/sec). Note, Lg group velocity is globally reported in the 3.4–3.6 km/sec range and Lg is the strongest local seismogram phase. Both Pg and Lg are crustal waveguide phases and the Pg and Lg wavelets represents energy transport in the crust taking place at average crustal velocities. Beyond 400 km Pg is often weak and may be replaced by first arriving Pn phases. Pg and Lg attributes, useful for epicenter determinations, are arrival times tied to maximum wavelet amplitudes. These parameters are easily extractable in an automatic manner from signal detector segmented records and an epicenter can be determined by ordinary methods. We have tested this novel analysis approach on network data from Norway, Finland, Germany, Italy, Israel, and USA using the same travel time curves. When comparison with known location could be made (quarry blasts etc), our envelope based epicenters locations were often better than those reported in local bulletins.

BAYESIAN LOCATION OF SEISMIC SEQUENCES IN 3D VELOCITY MODELS

C. Troise, P. Capuano and **G. De Natale** (Osservatorio Vesuviano,via A. Manzoni,249, 80123 Napoli, Italy)

A method is presented to compute earthquake density functions by summation of lo cation probabilities of individual seismic events estimated by a Bayesian procedure. Probability densities on the space locations of individual events are computed i n threedimensional velocity models. A Bayesian procedure is used, involving the computation of the conditional probability over a grid spanning the whole considered volume for the parameter s pace. Summation of probabilities for all the events of a given sequence gives earthqua ke densities in the zone of interest, from which other marginal probabilities can be computed. The r epresentation of seismic sequences in terms of a continuous variable gives a better insight in ma ny problems connected with the seismotectonic interpretations of earthquake sequences. The c omputation of the whole probability functions on the parameter space solves many problems connecte d with the computation of maximum likelyhood points, which have, intrinsically, different w eights and can also be strongly biased in case of ill conditioned solutions. Furthermore, the use of a continuous variable allows to develope rigorous testing procedures on the seismic networks, aimed to evidence and to homogenise, in some ways, the variable degree of location capability over the vo lume of interest. In the present version of the algorithm, the Thurbers ART2 simplified ray tracin g is used, because of its high speed and robustness. The method has been applied to the volcanic earth quake sequences occurred at Somma-Vesuvius and at Campi Flegrei caldera (Italy).

ENVELOPE PROCESSING SCHEME FOR AUTOMATIC LOCAL EVENT LOCATION.

Pinsky V.I.

Conventional network location algorithms, based on P and S first arrivals have following shortcomings: 1) it is often difficult to identify the proper phase: (Pg or Pn, Sg or Sn); 2) first arrivals are often masked by noise. The both factors may cause significant location errors. An alternative is to use other more reliable features of seismic energy time-distance distribution, forming relatively robust patterns. The dependency of this features on distance can be described by a few number of parameters, estimated from a sample of source station intervals observed in a large enough set of events. As a result we obtain parametric empirical travel-time curves , which serve for automatic epicenter determination through a fitting to measured features of energy distribution at different stations of the network. In the study based on a limited number of Israel Seismic Network records the seismic energy distribution was presented by curves of moving window RMS and hi-square optimal detector, having local maximum for P and S parts of seismogram. The corresponding P and S time moments versus distance functions were approximated linearly for a set of relatively strong local seismic events originated in the Galilee province of Israel. Travel time inversion was provided using grid search procedure. As a result for a set of rather weak local events from different parts of the country we have got accuracy of epicenter estimation +-6 km, satisfactory for automatic event location.

CALIBRATION STUDIES FOR GSETT-3 ALPHA STATIONS

K. Koch (Federal Institute for Geosciences and Natural Resources, Stilleweg 2, D-30655 Hannover, Germany)
U. Kradolfer (Swiss Seismological Service, ETH-Hoenggerberg, CH-8093 Zürich, Switzerland)

Using the database provided by the Reviewed Event Bulletins (REBs) for the first 18 months of the GSETT-3 experiment, we compiled mislocation patterns for arrays and selected three-component stations of the Alpha network from the published slowness and azimuth information gained through f-k- and polarization analysis. Imposing constraints such as a minimum signal-to-noise ratio (SNR) and number of defining phases we aim at eliminating location bias as the hypocentral parameters are taken from the REBs. Results from 14 arrays with apertures from about 1 km to more than 20 km are presented as well as from 18 three-component stations which indicate that the mislocation patterns in many cases can improve location accuracy considerably. If these mislocation patterns are compiled to provide coverage of a sufficient portion of the slowness domain these empirical corrections can easily be applied prior to location processing. More thorough study is still required to show that corrections are able to reduce location bias as deduced e.g. from reduction in location error estimates.

FOCAL PROPERTIES OF SEISMIC SEQUENCES AROUND MYGDONIA BASI (N. GREECE)

B.G. Karakostas, E.M. Scordilis, B.C. Papazachos (Geophysical Laboratory, Univ. of Thessaloniki, GR-54006 Thessaloniki, GREECE)
Ch.A. Papaioannou (ITSAK,P.O. Box 53, GR-55102 Thessaloniki, GREECE)

The spatial distribution of seismic events associated with three seismic sequences, that occurred around Mygdonia Basin in September 1994, January-February 1995 and April-May 1995, with magnitudes of the main shocks ML=4.1, ML=4.3 and ML=5.3 respectively, as well as the focal mechanisms of the main shocks, show that these sequences were produced by normal faults. The strike of the faults ranges from NE-SW to almost E-W. All these faults are characterized by large dip angle and right lateral horizontal component. The T-axis of the maximum tension is almosxt horizontal with an approximately N-S mean direction, which is in agreement with the determined direction of the maximum stress field for the area. The determination of the hypocenters and the focal mechaninsms were performed on the basis of the recordings of the telemetry network of the Geophysical Laboratory of the Thessaloniki University. There is a strong evidence that the accurately located earthquakes with magnitudes ML>3.0, which occurred since 1981, when the seismological network of the Geophysical Laboratory was started, define well the seismic faults which produced the sequences under investigation.

AN AUTOMATIC METHOD FOR REGIONAL SEISMIC EVENT ANALYSIS INVOLVING SIGNAL PROCESSING AND NEURAL NETWORK TECHNIQUES

J. L. Plantet, R. Crusem and **Y. Cansi** (Laboratoire de Détection et Géophysique, Commissariat à l'Energie Atomique, BP 12, 91680 Bruyères-le-Châtel, France)

A method for automatic location of regional earthquakes recorded on a sparse net work of short-period vertical seismometers is presented. The process is divided into 3 steps:
- an event detector which analyses a set of single channel detections produced b y a classical STA/LTA algorithm;
- a refined phase arrival-time picking method combined with a neural network ana lysis to produce a set of phase-labelled arrival times;
- a location procedure based on a grid-search using a convergence criterion whic h counts the number of labelled arrival times matching the current location.

The different algorithms are presented in great detail and statistical results a re given with a comparison to a human made bulletin.

A NEW FILTERING TECHNIQUE FOR AUTOMATIC SEISMIC ESTIMATION BASED ON SPLIT WAVELETS

F. J. Sabadell (Civil Engineering School, Polytechnic University of Catalonia, Gran Capitán, E-08034 Barcelona, Spain)
M. A. Oliva and J. Badal (Geophysics, University of Zaragoza, Pedro Cerbuna 12, E-50009 Zaragoza, Spain)
F. J. Serón (Dept. of Computer Science, CPS, University of Zaragoza, María Luna s/n, 50015 Zaragoza, Spain)

A novel filtering technique for noise reduction, aimed to automatic analysis of seismic data, is presented in this paper. The method is based on the wavelet transform, which cut up data into different frequency components and enables to study each one with a resolution matched to its scale. We employ split wavelets transform along with multiresolution analysis instead of the more general approach called thresholding, which entails rough frequency definition. The idea of thresholding yields a viable approximation for automatic analysis since it consists in setting to zero all coefficients less than a particular threshold. In spite of its advantages, the large number of parameters involved in the performance makes it unsuitable f or monitoring purposes. However, the splitting technique takes some benefits from the multiresolution signal decomposition and results in more accurate analysis. For various test SNR, using different distributions of noise, the splitting technique performs co nsiderably better than thresholding. In addition, this new technique presents a number of computational advantages over the Fourier transform that makes it specially useful to monitor large amounts of seismic datasets.

LOCATING SEISMIC EVENTS BY USING INTERVAL ARITHMETIC TO GLOBAL OPTIMIZATION

Matti Tarvainen (Institute of Seismology, University of Helsinki, PO Box 26, 00014 Helsinki, Finland)
Timo Tiira (Institute of Seismology, University of Helsinki, PO Box 26, 00014 Helsinki, Finland)
Eystein S. Husebye (Institute of Solid Earth Physics, Allégaten 41, N-5007 Bergen, Norway)

A novel global optimization method to locate seismic events at regional distances is presented. The optimization based on interval arithmetic (*IA*) is found to be fast and reliable, and not prone to minimization failure as some earlier methods like genetic algorithms.

The theory is presented and results are shown. The locations obtained via *IA* are compared with announced exact locations of one Finnish and one Norwegian mine. The median error is as small as 4 kilometres, and all the locations are within 20 kilometres from the true position.

THE APPLICATION OF THE REAL TIME SOFTWARE PACKAGE FOR THE SEISMIC RECORD ANALYSIS IN EARTHQUAKE WARNING SYSTEM.

E.V. Sasorova (State Oceanographic Institute, Kropotkinsky per.6, Moscow, 119838, Russia)

The method of the automatical determination of the faint modification of the seismic process based on the analysis of the records of the broadband digital seismic stations was developed. The software works in real time and it is based on the application of the self-adaptive algorithm, used the pattern recognition and fuzzy set methods and the slip-windows system. A set of numerical characteristics for every window's position calculated during the data processing describes the amplitude, frequency and statictic features of the curve. Now we use 16 characteristics This software package was tested in the field survey on Kuril Islands.

SE9 Seismic and teleseismic studies of the lithosphere

Convener: Achauer, U.
Co-Convener: Perchuc, E.

DEEP SEISMIC STRUCTURE OBTAINED BY OBS's EXPERIMENT IN THE TSUSIMA BASIN, THE JAPAN SEA

Argentov V.V.*,Suk B.-Ch.**, Anosov G.I.*,Bikkenina S.K.*,
Zhigulev V.V*., Zhiltsov E.H.*,
*IMG&G. Yuzhno-Sakhalinsk, 693002, Russia **KOR&D Institute, Ansan, P.O. Box 29. Korea

Crustal structure of the Tsushima Basin has been studied by OBS's experiment. The seismic refraction survey in five lines was carried out in 1991,1993 (total length of 770km.) of the Korea-Russian Co-Research Program. The seismic waves were recording by 33 OBS's, deployed at intervals of 10-20 km along five lines. The maximum long of the traveltime curves provided by using air-gun of big volume(30 , 60 litres) are fitted 80 km. The interpretation technique was provided by forward modelling using the ray theoretical method. P- and S-waves were analysed in detailed and the two-dimensional P-velocity model of the crust was constructed. The three main block of crustal structure were determined in the studied area.The Korean Plateau and continental slope(1) Tsushima Basin (2) and the region of the trough, located between the Korean Plateau and the Oki rise (3).The Tsushima Basin has complicated crustal structure.The presented data do not allow to answer definitly to the question concerning the geological genesis of the Tsusima Basin. One can say only that in the crust structure there are none visual indications of the basin generation by spreading. An existing information is in agreement mostly with hypothesis that the basin was generated as a result of "basification" of continental crust.

SEISMIC REFLECTORS IN THE MANTLE LITHOSPHERE BENEATH THE BALTIC SHIELD AND NORTHERN TORNQUIST ZONE

N. Balling, Department of Earth Sciences, Geophysical Laboratory, University of Aarhus, Finlandsgade 8, 8200 Aarhus N, Denmark

The deep seismic reflection profiling technique has proven to be able to resolve fine scale structures not only from the deepest parts of the continental crust and the crust-mantle boundary, but also in the sub-crustal lithosphere. Seismic reflectors in the mantle lithosphere have been observed beneath the major tectonic units of NW Europe including the Baltic Shield, the Tornquist Zone and the North Sea Basins. Dipping and sub-horizontal events are observed with dipping events sometimes closely related to structures at lower crustal and Moho level and sub-horizontal events so far observed, mainly in the deeper parts of the lithosphere. The characterization of these events, in particular the dipping events, in terms of genetic relations to crustal features, depth into the uppermost mantle, and age relations have very important implications for understanding the physical nature and depth extent of the continental plates and principal dynamic processes within the lithosphere-asthenosphere system.

$P-S$ CONVERSIONS FROM THE TOP OF THE NAZCA PLATE AND THE OVERLYING CRUST (NORTHERN CHILE)

G. Bock, A. F. Rudloff and F. Graeber (GeoForschungsZentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany)

We use a delay-and-sum technique to enhance weak $P-S$ converted phases from about 200 intermediate-depth earthquakes located just beneath the temporary 1994 PISCO network of 28 broad-band and short-period stations. The earthquakes studied are located in the subducted Nazca plate beneath northern Chile and northwestern Argentina. The bandpass-filtered (0.5 - 2 Hz) three-component recordings were rotated into the orthogonal ray coordinate system L, Q and T where L is along the ray of the incident P wave. $P-S$ conversions normally are recorded on the Q component which is transverse to L. Deconvolution of the P wave signal on the L component was carried out to equalize source signals. The inverse P wavelet was then used to deconvolve the Q and T components. For each station the seismograms were aligned on the maximum of the deconvolved P signal and then stacked after appropiate time shifts were applied that depend on conversion depth (assumed to be between zero and 100 km) and source location. The results can be summarized as follows: (1) strong $P-S$ conversion in the upper crust are seen in the active volcanic arc probably caused by partial melting; (2) conversions from the Moho at depths of about 60 km are seen at some stations; (3) relatively strong $P-S$ converted phases are seen from about 50 km depth at a coastal station. They probably originate at the top of the Nazca plate suggesting that this must be a sharp boundary.

TEMPORARY TELESEISMIC TRANSECTS ACROSS THE APENNINES

C. Chiarabba and A. Amato, R. Azzara, M.G. Ciaccio, G.B. Cimini, M. Di Bona, F. Lucente, L. Margheriti, C. Nostro, and G. Selvaggi (Istituto Nazionale di Geofisica, 00143 Rome, Italy)

In the past years, the deployment of temporary arrays that allows to record broadband waveforms of teleseisms and regional events had became a very powerful tool to investigate the structure beneath specific regions. These experiments are intrinsically multidisciplinary and different seismological analyses are independently used to jointly define the structure of the lithosphere underneath the array. We present here description and results of our experiments carried out in 1994 and 1995 across the northern and central Apennines in the frame of project GeoModAp, funded by the E.C. (contract EV5V-CT94-0464). Two linear arrays crossing the Apennines and consisting of 10 and 15 seismic stations equipped with broad-band sensors were continuously recording for about five months. The teleseismic recordings have been used to refine tomographic images, to individuate the main velocity discontinuities underneath each stations through the receiver functions techniques, and to investigate seismic anisotropy from SKS and S shear-wave splitting. The integration of these analyses allows us to recognize an high-velocity slab subducting beneath the Apennines, a complex geometry of the Moho, and a strong seismic anisotropy in the uppermost mantle consistent with results obtained in other mountain belts. Our results permit to constrain the geodynamic evolution of the Apenninic region.

EURASIAN PHASE VELOCITY, CRUSTAL THICKNESS AND SHEAR WAVE VELOCITY STRUCTURE RELATED TO RELIC AND ACTIVE TECTONICS

A. Curtis, R. Devilee, J. Trampert and R. Snieder (Department of Theoretical Geophysics, Universiteit Utrecht, Postbus 80.021, 3508 TA Utrecht, Netherlands)
B. Dost (ORFEUS Data Center, Utrecht, Netherlands)

Over 25,000 seismograms recording surface waves traversing Eurasia were inverted for phase velocity dispersion in the period range 20–250 s using fully automated methods from global seismology. Dispersion measurements were back-projected into Love and Rayleigh phase velocity maps across the whole of Eurasia; these in turn were inverted for shear velocity structure with depth. The resolution attained is demonstrably far higher than that available in global studies, and approaches that of regional studies, especially within Europe and central and southern Asia. Large scale tectonic features such as platforms and shields, subduction zones and back-arc spreading centers, roots of various mountain ranges and even narrow zones of intense deformation are clearly visible. An inversion for crustal thickness using a neural network displays a higher resolution than is available in most *a priori* moho depth maps. Hence, this study has produced S wave models of the Eurasian crust and upper mantle of similar resolution to P wave models allowing possible future joint interpretation. In addition, the resolution is now sufficient to make continental scale seismology a suitable tool for large scale crustal and lithospheric structural mapping.

3-D MANTLE FABRIC BENEATH TIBET

K.P. Furlong (Geodynamics Research Group, Geosciences, Penn State Univ., University Park, PA 16802, USA)
T.J. Owens (Dept. Geol. Sciences, Univ. South Carolina, Columbia, SC USA)

Although the gross-scale plate kinematics of the Himalaya-Tibet region are relatively well resolved, our understanding of how the Asian and Indian lithosphere have accommodated these kinematics is unresolved and hotly debated. Seismological observations can place constraints on both the large scale kinematics and the details of lithospheric deformation. We have used observations of shear-wave splitting and other indicators of a lattice preferred orientation (LPO) of the uppermost mantle beneath Tibet to place constraints on strain within this plate boundary region. In particular, observations of shear-wave splitting and Pn travel times within the Tibetan Plateau indicate that not only is there an LPO developed, but the orientation of the fabric across the northern plateau varies relative to the horizontal. Previous studies have identified a systematic pattern of orientation of the horizontal component of the fast direction which varies smoothly across the northern plateau. Our results indiate that the 3-D orientation of the fast direction shows a more complexly varying pattern. The mantle fabric increases in dip from north to south across the plateau, with a near horizontal orientation to the shear plane at the northern edge of the plateau which becomes near vertical in the region north of the Lhasa block. Within the plateau from N to S, the orientation of strain appears to vary from ESE to SSW and the inclination of the [100] direction increases.

The common inversion of the seismological and DSS data - New traveltime tomography method and results for Europe

V. Geyko. Institute of Geophysics, National Academy of Sciences of Ukraine, av. Palladin 32, 252680 Kiev-142, Ukraine

A new traveltime tomography method based on the Taylor approximation of wave equation and eikonal equation solution has been worked. It is shown that this approach has the significant preferences over the usual linearization method. The method is easily applied to interpret 3-D data of seismology and 2-D DSS. We examine processing and inversion of the observed seismic data by new method. The fundamental detailing of 3-D P-velocity model of the mantle based on the data from the Bulletins of the ISC is possible only when use following additional data on traveltimes of P-wave for every region. (1) The first and consequent arrival times observed on long-range and DSS profiles. (2) The data (absent in the Bulletins of the ISC) on the first and consequent arrival times from a weak near earthquakes recorded stations of the regional seismic networks. (3) The consequent arrival times in the range of epicentral distances of 12-25 degree determined from records of major earthquakes. (4) The first arrival times from the Bulletin of the ISC for teleseismic distances. Employment of the data of points (1) and (2) enables detailing of the structure of the lithosphere and asthenosphere. Those of points (3) and (4) permit specifies the depth and the character of the 410 and 670 km discontinuities. The obtained 3-D P-velocity model of the mantle beneath north Europe (particularly TESZ) is considered.

AZIMUTHAL DEPENDENCE OF Pn VELOCITIES IN THE MARMARA REGION

R. Gök, N. Türkelli, G.Horasan (Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Çengelköy 81220, İstanbul, Türkiye)
A. (Boztepe)Güney, (Istanbul Technical University, Maden Fakültesi, Jeofizik Mühendisliği Bölümü, Ayazağa-80626, İstanbul,Türkiye)

The Marmara Sea Region is on the westward continuation of the North Anatolian Fault Zone (NAFZ). The tectonic behaviour of the region is complicated, because it is a transition zone between the strike-slip pattern of the NAFZ and the extensional regime of the Aegian Region. The dependence of Pn velocities on azimuth reveals subcrustal anisotropy which is probably due to the frozen-in orientations of minerals and is related to past lithospheric tectonic activity. The data for this study are more then two thousand earthquake records from 14 stations of the Kandilli Observatory and Earthquake Research Institute in the Marmara Sea Region. Pn is calculated from the derivative of travel-time with respect to distance for pairs of stations aligned at the same azimuthal path. This method is more advantegous in that, it eliminates the travel time errors as a consequence of the location of epicenters. The accuracy of the results is tested by statistical methods. The variation of Pn velocity at uppermost mantle with azimuth is interpreted in terms of lateral variations of Moho topography and anisotropy. More reliable results are to be expected from future studies that make use of the velocities provided here.

TELESEISMIC SHEAR WAVE SPLITTING ACROSS THE ALTYN TAGH FAULT

G. Herquel (Ecole et Observatoire des Sciences de la Terre, Strasbourg, France)

A temporary seismic array has been operating in Northern-Tibet and Tarim during 5 months in 1995-1996. Twenty-four 5 seconds 3-component stations of the French Lithoscope program were deployed mainly along a NW-SE profile crossing the Altyn Tagh strike-slip fault. SKS and SKKS phases were analyzed. For all stations located on the western side of the Altyn Tagh, the fast polarization directions (FPD) are parallel to the fault direction with an average delay time of 0.6 second. East of the Altyn Tagh, the FPD rotate to an East-West direction parallel to the regional topographic direction suggesting a correlation between the regional topography and the mantle flow. The average delay time is the same as on the western side of the fault.

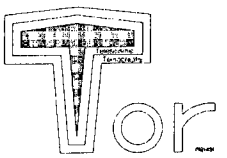
SHEAR WAVE SPLITTING, ANISOTROPY AND UPPER MANTLE CONVECTION BELOW GERMANY AND ADJACENT AREAS

Klinge, K., Brechner, S., Plenefisch, T., Krüger, F. (SZGRF, Krankenhausstr.1, 91054 Erlangen, Germany)

SKS-phases observed at the broadband stations in Germany show significant shear wave splitting. We have analyzed SKS and SKKS phases for shear wave splitting from 13 stations of the German Regional Seismic Network (GRSN), from 3 three-component stations of the Gräfenberg array (GRF) and from one Austrian station (SQTA). The azimuthal variations of the splitting parameters (fast axes ϕ and delay time between fast and slow shear wave δt) at several of the stations can be explained by two-layer anisotropic models with horizontal symmetry axes. The best resolved two-layer model is the GRA1 model (upper layer: ϕ =40°, δt=1.15s; lower layer: ϕ=115°, δt=1.95s). The upper layer can be attributed to the lithosphere. Because of the magnitude of the delay time of the upper layer the lower layer must lie within the asthenosphere. The fast axes in the lower layer is usually interpreted as the flow direction of the asthenosphere.
Our general findings from the GRSN Stations are an EW direction for the asthenospheric flow in areas of low lithosphere-asthenosphere boundary topography and in northeastern Germany a flow direction following the strike of the Tornquist-Teisseyre zone, i.e. an area with rapidly increasing lithosphere thickness. For the first time we have found also strong indications for inclined symmetry axes for at least two stations (GRB1, WET).

LITHOSPHERE STUDY VIA TOMOGRAPHY IN NORTHERN EUROPE, PROJECT TOR.

The Tor working group, reporter Soren Gregersen, KMS, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark.



The field work of the Teleseismic Tomography experiment across the Tornquist Zone, for short called Tor like the Nordic God, is nearing completion. The project is carried out by a working group with scientists from 9 European countries and USA. It goes across the most prominent geological border line in Europe, the Tornquist Zone, which cuts through Denmark, Sweden, Poland, Ukraine and Romania and has in previous studies shown large lithospheric differences to the project depths of 200-300 km. Tor is part of the Trans-European Suture Zone project of the Europrobe program. A preliminary experiment with 24 broad band seismographs as well as this winters campaign with nearly 150 seismographs show differences as well as similarities in seismic P and S wave signals across the zone. A feasibility study on beforehand showed that the expected lower lithosphere differences can be resolved. The investigation could be called 2½ dimensional, because a band of seismographs, rather than a line, makes an antenna which assures that earthquakes somewhat off the great circle can be utilized. The full interpretation is it too early to know, but this talk will update you on our results.

3D-IMAGE OF THE CRUST-UPPER MANTLE STRUCTURE FOR SOUTHERN FINLAND

T. Hyvönen and J. Malaska (Institute of Seismology, POB 26, FIN-00014 University of Helsinki, Finland)

A mean velocity-layer model is derived for the central southern Finland region. The results of DSS-profiles: SVEKA, BALTIC and FENNOLORA are combined to sets of constraints for depths and velocities of 1D layered structure. The target area (400 km × 400 km) is divided into three subregions following the main features of Moho-depth contour map of the area. First onsets and reflections of P-waves from crustal and Moho boundaries are measured from the records of DSS-shots at permanent seismic stations. The phases are fitted to traveltime curves under the DSS-constraints and new sets of 1D models are obtained for different subdivisions of the region. From the models four main layer boundaries (13-18 km, 27-35 km, 50-56 km and 74-80 km) are chosen and presented as smoothed, gridded volumes. The resulting image is discussed together with the main geological and geophysical information of the area.

ACTIVE SEISMIC TOMOGRAPHY OF THE CRUST IN THE NORTHERN PART OF GRAN CANARIA

Sebastian Krastel (GEOMAR, Wischhofstr. 1-3, 24148 Kiel, Germany)

Seismic data were collected during METEOR cruise 24 in an active combined land-sea experiment in the northern part of Gran Canaria, Canary Islands, up to 60 km away from the coast. Two 32-liter airguns served as seismic source; the energy was recorded by 7 ocean bottom hydrophones and 8 landseismographs. The p-wave first arrival times were inverted using the program simulps of Thurber (modified by Evans and Eberhart-Philipps). The vp-model obtained for the area fits well with the data.
The volcanic island is characterized by its heterogeneous structure with lateral velocity variations. Low p-wave velocities are associated with the Miocene syenitic feldspar-rich core, whereas the younger mafic plutonic rocks show a significantly higher velocity. The structure of the crust becomes more homogeneous as the distance from Gran Canaria increases. The only 4-km-thick igneous oceanic crust is covered with some 6-8 km of sediments.

VARNET: A SEISMIC PROFILE ACROSS THE VARISCAN FRONT AND THE IAPETUS SUTURE IN SW IRELAND

M. Landes and A.W.B. Jacob (Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin 2, Ireland)
F. Masson and C. Prodehl (Geophysical Institute, Univ. Karlsruhe, Germany)
VARNET Research Group (Denmark, Germany, Ireland)

As part of the VARNET project three seismic refraction lines were recorded in June 1996 across the Variscan Front in southwestern Ireland. Along line A, 171 seismic stations at 1 km intervals were deployed from Kinsale in the South to North County Clare. Two additional lines were recorded further west. A total of 34 shots were fired, including 23 shots which also served as off-line fan shots. This contribution is a preliminary interpretation of line A.
The line is about 175 km long, and the maximum range, with off-end shots, is about 190 km. The line crosses the postulated tracks of both the Iapetus Suture and the Variscan Front. These are separated by about 60 km on this profile. Though the Suture zone is certainly a deep feature, the nature of the Variscan Front has been the subject of study and discussion over many years. Its structure, whether for instance it is a thick-skinned or a thin-skinned feature, is not known.
Preliminary results indicate that the crustal structure is variable, though the Moho depth is constant at about 32 km throughout. A significant change takes place between the Variscan Front and the Iapetus Suture. The basement, the upper layer of a three layer crust, thickens to the North and the model reveals lateral changes in velocity.

SEISMIC WIDE-ANGLE OBSERVATIONS OF THE ANCORP-PROJECT IN THE CENTRAL ANDES

Lueth, S. (FU Berlin (1)), Lueschen, E. (GFZ Potsdam (2)), Schmitz, M. (1), Wigger, P. (1), Araneda, M. (U de Chile, Santiago), Giese, P. (1), Luterstein, R. (CNEA, Buenos Aires), Mechie, J. (2), R÷ssling, R. (SERGEOMIN, La Paz), Schulze, A. (2) and DEKORP-Research Group

The seismic observations realized during the ANCORP '96 field campaign (near-vertical reflection and wide-angle refraction measurements) are embedded in a net of seismic wide-angle observations obtained during the 80s and early 90s in the Central Andes. Wide-angle data are available now from the Nazca plate to the Chaco region in the Andean foreland over a 1000 km long (E-W) and 500 km wide (N-S) region in the Central Andes. The field campaigns realized during the CINCA '95 and the ANCORP '96 projects provided densly spaced recordings with geophone group intervals of 100 m for a transect at 21 S from the Nazca plate to the Altiplano. Shot point distances varied between 30 to 60 km for the ANCORP project. The principle characteristics of the crustal structure in the Central Andes, obtained by seismic wide-angle measurements, are the Moho dipping from 40 km depth in the foreland to 70 km beneath the Altiplano/Eastern Cordillera boundary, accompanied by a decrease in average crustal velocity from 6.3 km/s to 6.1 km/s. In the forearc, the crustal base decreases in depth from 70 km beneath the Precordillera to 30 km beneath the Coastal Cordillera. The Moho of the subducting Nazca Plate is imaged by overcritical reflections from the coast up to the Precordillera.

AN APPROACH TO THE ANELASTIC STRUCTURE OF THE MEDITERRANEAN BASIN FROM RAYLEIGH WAVES ATTENUATION

Martínez, M.D. and Lana, X. (Univ. Politècnica de Catalunya, Spain)
Canas, J.A. (Univ. Politècnica de Catalunya, Spain)
Badal, J. (Univ. de Zaragoza, Spain)
Pujades, Ll. (Univ. Politècnica de Catalunya, Spain)

An approach to the Q^{-1}_{β} structure of the Mediterranean basin is obtained by multiple filtering analysis of Rayleigh wavetrains recorded at pairs of MedNet broad-band stations with teleseismic paths along great circles connecting seismometers and epicentres. Due to the current path coverage offered by the set of seismic paths, we can only attempt for the moment a grouping of seismic paths covering similar tectonic structures and the stochastic inversion of the corresponding fundamental mode averaged attenuation coefficients.

ANCORP '96 - A DEEP SEISMIC REFLECTION SURVEY IN THE CENTRAL ANDES AT 21 S

Lueschen, E. (GFZ Potsdam (1)), Schmitz, M. (FU Berlin (2)), Wigger, P. (2), Araneda, M. (U de Chile, Santiago), Bribach, J. (1), Chong, G. (UCN, Antofagasta), Giese, P.(2), Grunewald, S. (1), MartÝnez, E. (YPFB, Santa Cruz), Oncken, O. (1), R÷ssling, R. (SERGEOMIN, La Paz), Ryberg, T. (1), Schulze, A. (1), and DEKORP-Research Group

A deep seismic near-vertical reflection profile was conducted from the northern Chilean coast at about 21 S over 400 km to the eastern border of the Altiplano in southern Bolivia between 15th Sep. and 20th Nov. 1996 in a joint venture by German, Chilean and Bolivian institutions. The objektive was to image the structure of the western margin of the Central Andes crossing the forearc region, the actual magmatic arc and the Altiplano high plateau. A further important target was the subducting Nazca plate. The data acquisition was done by a moving, 252-channel recording spread with 100 m geophone group intervals. Borehole blasts with 90 kg explosives each were fired at both ends of the spread and every 6.3 km distance, resulting in a 4-fold-CMP-coverage. The near-vertical measurements were integrated with wide-angle observations of 9 multiply fired shotpoints and mine blasts. For the first time, strong eastward dipping reflections were obtained from the mantle of the Nazca plate. Prominent continental crustal reflectivity is observed at 12 s TWT with a westward dip correlating with the west of the magmatic arc. Beneath the Altiplano the continental crustal base is marked by strong decay of intracrustal reflectivitiy at about 20 s TWT.

CRUST AND UPPER MANTLE STRUCTURE OF THE MEDITERRANEAN BASIN FROM LOCAL RAYLEIGH WAVE GROUP VELOCITIES

Martínez, M.D. and Lana, X. (Univ. Politècnica de Catalunya, Spain)
Badal, J. (Univ. de Zaragoza, Spain)
Canas, J.A. and Pujades, Ll. (Univ. Politècnica de Catalunya, Spain)

The analysis of Rayleigh wavetrains recorded at the MedNet broad-band stations led us to obtain recently a set of regional group velocity maps, for the fundamental mode, in the period range 15-80 s. The exhaustive application of the stochastic inversion algorithm leads us to obtain at present 3-D shear velocity models down to 250 km depth for all the places of the basin with a minimum resolving power. The models obtained enhances the differences between the eastern and western parts of the basin, with the bottom of the asthenosphere down to 225 km depth for the whole basin and the top down to 60-80 km depth. A resolving degree is defined for each point and each layer according to the resolving kernels derived from the set of inversions.

VARNET: SEISMIC PROFILES ACROSS THE MUNSTER BASIN AND THE VARISCAN FRONT IN SW IRELAND

F. Masson and C. Prodehl (Geophysical Institute, University of Karlsruhe, Germany)
M. Landes and A.W.B. Jacob (Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin 2, Ireland)
VARNET Research Group (Denmark, Germany, Ireland)

The VARNET Project included two seismic refraction profiles and one shorter splay line in southwestern Ireland. A total of 34 shots were fired, including 23 shots which also served as off-line fan sources. This poster describes the preliminary results from the western line B and the splay line C.
Line B crosses the westernmost peninsulas of Ireland extending from Roaringwater Bay in the South to the Shannon River estuary in the North. This allowed closely spaced shots. 109 stations were deployed at about 1 km intervals and the total length of the line, including off-end shots, was about 120 km. In addition a splay line of 21 stations was recorded across a gravity low in the northern Munster Basin.
The upper crustal structure is very variable and is generally slower in the South than in the North. The middle crust is approximately 10 km thick and is bound by two reflecting horizons at about 12 and 22 km depth. The total crustal thickness is about 32 km. In the southern part of this line some intermediate reflectors are observed, dipping to the South. The Variscan Front seems to be evident on the seismic sections for line B where variations in the arrival time of the Pg occur.

EARTH CRUSTAL MODELLING FROM SYNTHETIC SEISMOGRAM. FIRST RESULTS.

R. Mauricio, J.A. Canas and Ll. Pujades, ETSICCP, U. P. de Catalunya, Barcelona, Spain.

In this work, the crustal structure of Catalonia has been modeled using synthetic seismograms. For this purpose, some recent earthquakes occurred in the southeastern coast of Catalonia and registered by the seismic station situated at the northernmost part of the country (the Pyrenean Mountains) have been taken into account. Thus, the crustal structure along a profile that crosses the whole region has been determinated.
The synthetic seismograms have been obtenaid in the temporal domain by means of the generalitzed ray and also using the asymptotic ray theory. Two crustal models have been considered: first, the standard model for the Iberian peninsula, and on the other hand the ECORS reflection seismic model.

IMAGING THE EARTH CRUST STRUCTURE IN EAST ANATOLYA

Ergeshev T.,Burnashev R.S.,Ferdman N.A.,B.S.Nurtaev (Institute of Geology and Geophysics,N.Khodjibaeva 49,Tashkent 700041,Uzbekistan)

Field work has been carried out in Erzinjan depression (Turkey,1992) along profile of NE orientation Erzinjan - Kale (100 km) with distance between seismic stations 5 km. In this study we present results of our interpretation of obtained travel times curves, and Earth crust structure using records of 20 local and distant earthquakes. Our method is based on joined interpretation of reflected, refracted and converted waves. The thicness of the Earth crust is defined in Erzinjan depression as 39 -41 km, to the west of depression 48 - 54 km, to the south - 46 - 50 km, and to the south - east 46 -58 km. The Anatolian deep fault is trassed from sout - east to north west with vertical amplitude on M discontinuity 5 - 10 km. We defined 8 - 9 layers with seismic boundaries within the Earth crust of East Anatolya. The thickness of upper earth crust in this region obtained as 26 - 28 km. Also we present comparison of imaging the Earth crust structure in Syr - Darya depression (Turan plate, Uzbekistan) obtained 1) using converted P and S waves analysis of local and distant earthquakes and 2) using traditional deep seismic sounding data.

2-D MODEL OF THE LITHOSPHERE ALONG RIFT PROFILE, SIBERIAN CRATON

Pavlenkova G.A., Institute of Physics of the Earth, B.Grusinskaja, 10, Moscow, 123810, Russia
Solodilov L.N., GEON Centre, Chistiy 10, Moscow, Russia

The GEON Center carried out several long-range seismic profiles using peace nuclear explosions (PNE). 2-D model of the lithosphere was constructed for one of the profiles, RIFT, crossing the Siberian craton and their boundaries with the Pur-Gedan basin of the West Siberian platform and with the Baikal Rift Zone. The model shows a strong horizontal inhomogeneity of the crust and uppermost mantle both inside the craton and at its boundaries with the rift zones. The Pur-Gedan basin has a thick low velocity sediments and thick high velocity crust, the Siberian craton is divided in two parts with higher velocity in the north and lower velocities in the south, the Baikal Zone crust is similar to this southern part of the craton. The uppermost mantle is characterized by variation of the velocities beneath the Moho from 7.8-8.0 km/s in the young West-Siberian platform and in the Baikal Zone to 8.1-8.6 km/s beneath the Siberian craton. Anomalously high velocities (8.5-8.6 km/s) were outlined beneath the Tunguss basin and in the south part of the craton. In this part a zone of velocity inversion is also observed at depth of 100 km, it is underlined by the strong reflector. The inversion is located inside the thermal lithosphere which thickness reaches 200 km beneath the Siberian Craton. Several boundaries were also distinguished at depths of 200, 250, 410, 680 km.

THE TRANSITION FROM "COLD" TO "HOT" AREAS OF NORTH AMERICA COINCIDES WITH HIGH-SEISMICITY ZONES - REINTERPRETATION OF EARLY RISE SEISMIC DATA

E. Perchuć (Institute of Geophysics, Polish Academy of Sciences, ul.Ksiecia Janusza 64, PL-01452 Warsaw; Poland)
H. Thybo (Geological Institute, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark)

Reinterpretation of the long-range seismic sections of the Early Rise experiment identifies a characteristic delay of refractions from below the Lehmann discontinuity on several profiles. The delay is identified at the far end of the lines and coincides with a transition from continuous, homogeneous first arrivals to seismic phases, which are scattered in traveltime and amplitude. The change in character resembles the change observed at the Seismic 8° Discontinuity. Modelling shows that the delay in Lehmann refractions occurs near the transition from the plains to mountainous areas on the west-striking Early Rise lines. Therefore, we interpret the characteristic delay as caused by the transition in seismic structure between "cold" and "hot" areas at > 200 km depth. The c. 50 km wide transition zone coincides with high-seismicity zones on most profiles, except on the lines fully within the "cold" craton where seismicity is sparse. The coincidence between a transition below c. 200 km depth and zones of crustal earthquakes indicates that the existence of such deep zones may have strong effects on shallow, local tectonics.

UPPER MANTLE ANISOTROPY BENEATH THE TRANSITION ZONE OF MOLDANUBICUM AND SAXOTHURINGICUM REVEALED BY SHEAR WAVE SPLITTING

Plenefisch, T., Klinge, K. (SZGRF, Krankenhausstr.1, 91054 Erlangen, Germany)
Kind, R. (GFZ Potsdam, Telegrafenberg A3, 14473 Potsdam, Germany)

The analysis of shear wave splitting of teleseismic SKS-phases is a powerful tool to investigate anisotropy in the upper mantle. The splitting parameters allow conclusions about the direction of the recent flow of the asthenosphere and about fossil orientation of anisotropic crystals in the brittle part of the lithosphere.
The goal of our project is to investigate small-scale lateral variations of the splitting parameters in the transition zone between Saxothuringicum and Moldanubicum. For that reason 25 broadband stations were installed from autumn 1995 to april 1996 in the region of the Vogtland and the Bavarian Forest. The stations formed a 200 km long and N-S oriented profile, which crossed the assumed suture zone of both tectonic units.
The analysis of the observed splitting of SKS-phases shows in general an E-W orientation of the fast axis of the anisotropic mantle material, but strong variations of the splitting parameters with respect to the azimuths of the incoming waves in direct vicinity of the suture zone. These variations are an indication of a complex mantle structure formed either by several horizontal anisotropic layers and/or by anisotropic layers with inclined symmetry axes. Moreover there is a rotation of the fast symmetry axis from WNW-ESE to WSW-ENE when going from the southern part of the profile (Moldanubicum) to the northern part (Saxothuringicum).

SEISMIC ANISOTROPY AND VELOCITY VARIATIONS IN THE MANTLE BENEATH THE SAXOTHURINGICUM/MOLDANUBICUM CONTACT IN CENTRAL EUROPE.

J. Plomerova, J. Sileny, V. Horalek, K. Spacek, J. Pospisil (Geophysical Institute, Czech Academy of Sciences, Bocni II, 141 31 Praha 4, Czech Republic; jpl@ig.cas.cz)
V. Babuska (UNESCO, Div. of Earth Sciences, 1, rue Miollis, 75 732 Paris, France, v.babuska@unesco.org)

A passive seismic field experiment at the western rim of the Bohemian Massif (May - December 1992) aimed at studying lateral variations of anisotropic structure across the contact zone of the Moldanubicum and Saxothuringicum in order to retrieve a 3-D anisotropic model of the lower lithosphere. Similarly to the results of the field experiment in the southern Sweden, which studied anisotropic structure of units separated by the Protogine zone, and to previous studies of the P residual spheres in central European stations, also this experiment showed a distinct change of the P residual pattern related to the contact of the Saxothuringicum and Moldanubicum. Mapping the upper mantle anisotropy based on the shear-wave splitting determined the high velocity directions beneath the the GRF array in azimuths close to the strike of the Variscan structures. In general, the E-W orientation of the fast shear-wave polarization is characteristic for stations in the central European region. The shear-wave splitting parameters detected by the experiment exhibit lateral variations along the array and show the contact of the Moldanubicum and Saxothuringicum as a broader transition zone.

PARTIAL MELTING AND ELASTIC WAVES - RESULTS OF EXPERIMENTAL IN SITU SIMULATION

K. Roetzler, D: Rhede, S. Raab and **H.J. Mueller** (GeoForschungsZentrumPotsdam, Telegraphenberg A6, D-14473 Potsdam, Germany)

The process of partial melting in natural rocks has a fundamental meaning for understanding the dynamics of the lithosphere. The well known low velocity zones are interpreted as such structures for the most part. On the other hand remarkable transportation of mass and energy is attained by melt migration. The paper demonstrates some new data for elastic compressional and shear waves measured under experimental simulated high pressure - partial melting conditions.

A high performance gas pressure vessel with a pressure limit of 2,500 MPa and a maximum temperature of 1,500 C was used for the experiments. The cylindrical shaped samples are encapsulated by welding to exclude any volatile exchange. The goal of the experiments is to find out the material-structural cause for the measured variation of physical data by post-experimental use of different microscopic methods, polarization -, electron scanning -, transmission microscope, digital image processing and microprobe.

VELOCITY HETEROGENEITIES OF TIEN-SHAN EARTH CRUST. NATURE OF INTERCRUSTAL WAVEGUIDES

T.M.Sabitova (Institute of Seismology,Asanbay 52/1,720060,Bishkek,Kyrgyzstan)

Interpretation of 3-D Tien-Shan crustal velocity model, obtained by means of tomography (Roecker,Sabitova et al., 1993) allowed to receive new notions about velocity peculiarities of crust had been unsufficiently studied before: on its disintegration and velocity differentiation, on difference between blocks composing the crust, on waveguides existing there at the different depths, on absence of uniform stretched boundaries between "layers". Presence of waveguides in crust is of a great interest, because it is with them may be relate the manifestation of different geodynamical processes, and particularly, seismicity. It was appeared, that source zones of majority of Tien-Shan strong earthquakes (M>6) are characterized with simultaneous presence of highvelocity bodies and waveguides, in first line - lowercrustal waveguides. The nature of waveguides revealed cannot be accounted for one mean. Velocities of body waves, travelling in crust depend on rock's composition and density, on thermodynamical conditions, fluid-saturation, mechanical and physical state of substance and other. In conditions of Tien-Shan accordingly to geothermic data available the forming of middle- and lower-crustal waveguides is related mainly with heating and partial melting of material.

ANISOTROPIC TOMOGRAPHY OF THE ATLANTIC OCEAN FROM RAYLEIGH SURFACE WAVES

Graça Silveira[1,2,3], E. Stutzmann[4], J.-P. Montagner[4] L. Mendes-Victor [1,2]
CGUL Rua da Escola Polit\'ecnica. 58, P-1250 LISBOA
Dep.de Fisica, FCUL, Edificio C1, Campo Grande. P-1700 LISBOA
ISEL Rua Conselheiro Emídio Navarro, P-1800 LISBOA
IPGP 4, place Jussieu, 75252 Paris Cedex 05, France

To improve lateral resolution of 3-D models under the Atlantic Ocean Rayleigh wave phase velocities have been determinated for 1311 direct epicentre to station paths. Phase velocities have been calculated by the technique of cross-correlation with a synthetic seismogram. The phase velocities have been inverted, without *a priori* constraints, to obtain lateral variations and azimuthal anisotropy for periods ranging from 52 to 250s. Shallow layer corrections have been applied. A good correlation between hot spot location and low velocity anomalies has been obtained.. The ridge axis correspond to a low velocity anomaly for short period. When period increases, the axis of the ridge seems to tend to a North-South direction defined by hot spot locations. The shields below Canada, Brazil and Africa correspond to a high velocity anomaly at short period and only Brazilian shield is still visible for the 200a period, suggesting that Canadian and African shields are shallower structures. Anisotropy directions are only interpreted in Mid-Atlantic area where we have the best resolution. The fast axis of Rayleigh waves is found perpendicular to the ridge axis and is consistent with the expanding direction of the envolved.plates.

ROLE OF SEISMIC MIGRATION COMPARATIVE ANALYSIS IN DEFINING SEDIMENTATION AREAS WITH COMPLEX STRUCTURE

Slobodan Stanić[1]
NIS-NAFTAGAS, Geophysical institute, Belgrade, Yugoslavia[1]
University of Belgrade, Faculty if mining and geology, Belgrade, Yugoslavia[1]

During the last decade, idea on modern approach to seismic migration based on seismic migration comparative analysis application before and after summing, by complex sedimentation areas defining, in order to determine structural-tectonic relationships and oil and gas discovering, was made and developed by the author. As a result of this approach to seismic reflective exploration, a processing flowchart based on seismic migration comparative analysis before and after summing has been developed. As most of complex algorithms of data processing and interpretation, the scheme means longer time of calculating, application of complex programs, and larger number of control seismic sections. As a result, more qualitative seismic section is possible to be obtained and, hence-more correct interpretation of investigated area.

STRUCTURE AND PHYSICAL STATE OF THE NORTH-WESTERN ITALY UPPER MANTLE

D. Spallarossa, S. Parolai, C. Eva and M. Cattaneo (Dipartimento di Scienze della Terra, Universita' di Genova, Italia)

Vp Structure of the litho-asthenospheric system of northwestern Italy and surr ounding regions, detected by teleseismic tomography, was used to compute temperature a nd density variations in the upper mantle. The obtained results, compared with other geophysical studies (Gravity and Heat flow density), allowed to improve the knowledge of the Alpine and Apenninic structure. In particular the continuity between the southward Alpine subduction and the lit hospheric roots imaged beneath the Po Plain was observed. Moreover a still active subduct ion beneath the Northern Apennines can be confirmed. We, in particular, focused our attentio n to determine the physical state of the mantle underlying the Ligurian Sea; the temperature anomalies calculated by the Vp variations, the observed high heat flow and the negative gravity anomalies suggest the presence of fractions of par tial melt at 120-160 km depth inside a particularly hot upper mantle.

TELESEISMIC P-WAVEFORM INVERSION STUDY OF THE EARTH'S CRUST IN THE EAST CARPATHIAN REGION

G. Starodub, A. Gnyp (Carpathian Div. .of Geophysical Inst., Ukrainian Acad.Sci., Naukova 3b, 290601, Lviv, Ukraine)

Complex inversion study of local crustal structure beneath several regional broadband seismic stations has been carried out. Sets of radial components of observed seismograms were inverted in the frequency domain to estimate layer thicknesses, P- and S-wave velocities and quality factors. The maximum availible apriory information (mainly from deep seismic sounding and geological data and previous inversion results) was used to determine mean initial models and put constraints on the range of model parameter change. The corresponding stochastic inversion procedure damping factors were used as the real multidimensional Gaussian process parameters to produce the sets of initial models. In order to improve the convergence of inversion procedure the number of free parameters in the initial 20-25 layer models was reduced in step by step way until the resolution matrices were close to unite ones and the number of layers was 4-5. The resulting models are compared to and discussed in connection with the initial ones and models determined for mean initial ones. The existance of low Vs layer at midcrustal depth (7.2-21.0 km) is confirmed for Uzhgorod model. Abrupt crust-mantle boundary at 51.3 km (as it was find out in our previuos inversion study) is proved for Kosiv model (instead of 43.0 km as it was assumed basing on common depth point data).

Velocity Anomalies of the Tectonosphere from a Long Geotraverse (L≈ 400 South Kuriles-Pribaikalie

Tarakanov R.Z., Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian Academy of Sciences, 693002, Yuzhno-Sakhalinsk, Russia
Omelchenko O.K, Computing Center of the Siberian Branch of the Russian Academy of Sciences, 630090, Russia.

A version of the tectonosphere P-wave velocity cross-section was constructed from a long geotraverse South Kuriles-Pribaikalie, basing on a great number of empirical data. The geotraverse crosses the structures with different histories of tectonic development.

The two-dimensional velocity cross-section, given on an irregular grid, was smoothly approximated, using algorithms of convex splines and decomposition of unit.The velocity model was refined by means of the iterative method using point-by-point comparison of theoretical travel time curves constructed by the ray method with the empirical ones.

It was established that the upper mantle area beneath the Sea of Okhotsk and Kuril region of active volcanism, is characterized by lower (up to 0.2-0.5 km/sec wave velocities. Relatively higher (up to 0.1-0.3 km/sec) P-wave velocities distinguished within the seismofocal zone and on its continuation up to depths a 1000 km. A depth up to Golitsin's boundary (h≈ 400 km) varies depending on tectonic history of the region.

Structural Peculiarities of the Kuril-Kamchatka Seismofocal Zone and Surrounding it Upper Mantle Blocks from Seismological Data

Tarakanov R.Z , Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian
Academy of Sciences, 693002. Yuzhno-Sakhalinsk, Russia

Heterogeneities in the medium structure and elastic properties within the Kuril-Kamchatka seismofocal zone are reflected in the peculiarities of deep distribution of maximum observed magnitudes (Mmax) of earthquakes and seismic wave velocities. 4 layers of the reduced strength were distinguished at depths 60-80 km, 120-150 km, 220-300 km, and 380-430 km within the seismofocal zone from Mmax = f (h). These layers alternate with the layers of the medium higher strength. It is shown that layers of reduced strength coincide in depth with layers of reduced velocity.

A generalized velocity model of the seismofocal zone structure and the adjacent upper mantle blocks up to a depth of 420 km was constructed. The area with an abnormally low P-wave velocity (δV_p = - 0.4 km/sec) is distinguished beneath the Sea of Okhotsk at depths of 100-200 km. A layer with an abnormally high P-wave velocity (δV_p = + 0,5 km/sec) is distinguished at depths of 340-420 km, identified by us with Golitsin's layer.

SEISMIC CODA WAVE ATTENUATION IN NORTHERN VENEZUELA (SOUTHEASTERN CARIBBEAN)

A. Ugalde; L. G. Pujades and J. A. Canas. Technical University of Catalonia, Barcelona (Spain).

The Caribbean-South America plate boundary in northeastern Venezuela has been studied in terms of coda wave attenuation. Seismic data were recorded by a microseismic array of 58 short-period, 3-component seismic recorders with a flat velocity response in the 2.5-39.2 Hz frequency range, and consist of 96 earthquakes with very low to moderate magnitudes, and depths ranging from 1 to 90 km. A multiple lapse time window analysis, based on the hypothesis of multiple isotropic scattering with uniform distribution of scatterers has been applied to the available seismic data in order to obtain the intrinsic and scattering attenuation in the region. Results show that the seismic albedo is very low for all the studied frequencies, so the intrinsic absorption is stronger than the scattering attenuation. A strong frequency dependence of the attenuation parameters have also been found. The studied area partially includes the El Pilar fault zone, which is believed to represent a transform fault between the Caribbean and South America plates. Total attenuation is strong in the region; this fact correlates well with the attenuation expected in active tectonic areas. Nevertheless, the low scattering attenuation seems to indicate that the physical processes that cause the strong intrinsic absorption are related to the proximity of the subduction zone east and south of the Lesser Antilles.

P- AND S-WAVE VELOCITY STRUCTURE BENEATH CENTRAL COSTA RICA

Z.S.Yao, R.G.Roberts and Q. Ronnie (Geophysical Department of Uppsala University, Villavagen 16, 752 36 Uppsala, Sweden)

Costa Rica is located in a complex, tectonically active region where the Cocos plate is subducting on the western margin of the Caribbean plate under Central America. The collision of the plates together with the interaction with the Nazca plate and the Panama block makes Costa Rica one of the highest seismicity regions in the world. Since 1984, the Costa Rica Volcanological and Seismological Observatory of the National University has been operating a permanent short period seismic network. There are 48 stations densely distributed in the central region. With this network thousands of earthquakes have been recorded, providing high quality of P- and S-wave arrival times of local eathquakes. To determine the 3D P- and S-wave velocity structure of the crust and upper mantle, we have applied a new tomographic method based on an adaptive regularized recursive least squares algorithm. Results show that in the crust the velocity structure is quite complex and a low velocity area corresponding to the volcano chain is resolved. The average velocity in the depth between 30 - 50 km is lower than expected. This result is consistent with a recent Pn wave velocity structure study. The low velocity structure may indicate the presence of partial melt in the upper mantle or may indicate that because of the shallow angle of subduction of the Cocos plate, oceanic crust in this area is thickened. Down to the depth of 100 km, a high velocity slab corresponding to the subducting plate of Cocos is observed.

OSCILLATORY PROCESSES IN THE EARTH LITOSPHERE

F.N.Yudakhin, T.A Bazavluk. Institut of Ecological Problems in the North, Urals Division of Russian Academy of Scs. Arkhangelsk, Russia.

On basis of the long-term studying, by method of earthquake converted seismic converted seismic waves, the situation of seismic boundaries in the lithosphere with stetionary seismostations appliance the changes of bedding depth of those boundaries in time is established. These changes are expressed in the form of fluctuations with periods from several months (6-12) up to several years and more and are characterized by amplitude up to 4-5 km. It is concluded that the existance of deformative waves in the lithosphere of the Earth are due to the sources which are its entrails. The observable waves, as appears, are one of the expression of general oscillatory processes in the Universe.

SE10 Deep seismics: methodological challenges and limitations

Convener: Prodehl, C.
Co-Convener: Pavlenkova, N.I.

METHODOLOGICAL CONSIDERATIONS OF 3-D CRUSTAL STRUCTURE MODELING BY 2-D SEISMIC METHODS

J. Ansorge, E. Kissling, F. Waldhauser (Institute of Geophysics, ETH Hoenggerberg, CH-8093 Zürich, Switzerland)
M. Baumann (GEOMAR, Wischhofstr. 1-3, D-24148 Kiel, FRG)

The large number of crossing seismic refraction and reflection profiles in the Alpine area allows to image the 3-D crustal structure. Most of these data were collected along profiles which implies for each one a 2-D interpretation. In the Alps, the validity of the 2-D interpretations can be controlled by means of crossing profiles and eventually be extended to a 3-D structure. This requires a carefully controlled migration in space. In order to relate structural features from one profile to the other, seismic phases or waves have to be identified on individual profiles as reflections or refractions from specific crustal elements. Fresnel volume calculations with dominant frequencies allow uncertainty estimates for specific structural elements. These values given for best-quality observations are modified by a weighting factor which includes data quality, orientation of profiles with respect to tectonic strike, and type of profile such as reversed or unreversed. Quantification of data uncertainties allows to calculate simplest models satisfying the data. Applied to the Alpine region a lateral continuous crust-mantle interface showing least surface roughness and highest continuity is modeled featuring interface offsets where required.

THE NEW METHOD OF PROCESSING AND INTERPRETATION OF MWCE-DSS DATA.

S.K. Barykin, I.A. Mushin

The processing methods' improvement of the received initial seismic material, by the method of converted waves from earthquakes - deep seismic sounding (MWCE-DSS), are of the first priority. The method structural-formational analysis (SFA), which is worked out for the sedimentary basin study and based on the idea of the hierarchic organized geological environment, operates by quantitative seismogeologic models and possesses of powerful automatic processing means. The stage of dynamic spectral study of MWCE data includes: the vertical and lateral spectral-time analysis (STAN), the range sections construction with the using of different technological procedures, and also the composition of the seismic parameters (amplitudes, frequencies, psevdovelocities etc.) sections. The creation of the two-range sections in the lateral STAN regime gives the most representative seismic information for the seismogeologic models of the earth crust. Experimental assaying of the MWCE data by SFA method along the geotraverses at the East-European platform showed, that it may be adopted to the specific of depth seismic materials. The inner structure of structural-deformative bodies and crust-mantle heterogeneities, listric faults attenuating in the different stratums of the earth crust, and subvertical parts of the seismic correlation loss, indentifying with the channels and wide depth fault zones are distinguished with confidence. The increase of inner "sloping bedding" with the depth, which is identified with strain and pressure anomaly zones is observed.

"BRIGHT SPOTS": MAGMATISM AND RHEOLOGY FROM INTEGRATED ANALYSIS OF DEEP SEISMIC DATA

Andrew Ross and Larry Brown (INSTOC, Cornell University, Ithaca, NY 14853)

Among the most intriguing observations from seismic profiling are anomalously strong reflections that have been interpreted as fluids, usually magma, deep in the crust. Moreover, comparable bright spots have also been reported from shear waves recorded by local earthquake networks, particularly in Japan. However, large amplitudes alone are not sufficient to establish a fluid origin, as mafic intrusions, tuning and geometrical focusing can give rise to unusually strong relative reflectivity. The case for fluids thus requires additional seismic analysis, and can be greatly bolstered by complementary geophysical data. These include: P wave polarity, S wave reflectivity, P&S AVO and magnetotelluric sounding. Most of the reported bright spots have been interpreted as magma based primarily on tectonic setting (although geodetic uplift over the Socorro, N.M., bright spot argues strongly for magma inflation). Although bright spots have been documented as shallow as 5 km and as deep as the Moho, the majority lie between about 15 and 20 km, or just below the seismogenic zone in active areas. Although density contrasts and structure have been proposed to control magma emplacement, we suggest that the aggregate reflection data most strongly support a rheological trap, and that bright spots represent a new means of mapping brittle-ductile transitions in the lithosphere.

INTEGRAL PRESENTATION OF TWO FIRST TERMS OF RAY SERIES

A.A. Duchkov (Novosibirsk State University, st. Pirogova 2, Novosibirsk, 630090, Russia)

Ray series is one of important tools in the theory of seismic wave propagation. Usual way to calculate different terms of the ray series is to solve corespondent transport equations. As a matter of fact it was done only for zero approximation and for addition component of first term. Standard ray series does not work in the vicinity of caustics. In this paper we suggest a new approach, which is based on well-known integral representations, containing Green's tensor, and ideas of method of discontinuities. According to this method, Green's tensor and wave field on the given surface can be represented only by their discontinuities maintaining descriptive importance of theory: it gives full geometric description of phenomenon under review. We have received explicit formulas for wave field presentation in particular point, if it is defined on reference surface, for both compression and distortion waves. This formulas are unique as they hold two term of ray series. It was a check of method before it is used for research of wave dynamics in caustic situations.

VELOCITY FILTERING IN DSS

Anatoly V. Egorkin (The GEON Centre,4, Chisty per , Moscow 119034, Russia)

For the most siesmic DSS profiles, information, concerning crustal and upper mantle velocity structure , had been obtained due to interpretation of the first arrivals (refractions) and the most prominant wide-angle reflections (in general, PMP). It is obvious that such an approach necessrily neglect the details of the crustal structure and do not allow to determine a unique velicity modal. For improving reflection phases correlation, the resolution, and signal-to-noise ratio of DSS data a RMS velocity and frequence filtering combination used by the GEON Centre. Output of the velocity filter is the set of trace sections for different constant RMS velocity from the desirable velocity field. In addition to the described processing the summing of the traces with different RMS velocity can be applied, mainly to improve correlation of reflections with time-distance curves differ from hyperbolae. Application of RMS velocity filtering to experimental data shows that this procedure allowed an easy identification of phases. Subhorzontal reflections as well as dipping ones were revealed. The prominent and lengthy (extending beyond distances of more than 20 km) artificial events were not observed. RMS velocity filtering of three component records, combined with analysis of wave field frequency spectra, considerably, helps to understand a waves nature. The velocity section obtained along profile URSEIS'95 illustrates possibilities of the new method.

INTRA-CRUSTAL ISOSTASY IN THE PRECAMBRIAN CRUST OF THE BALTIC SHIELD AND AUSTRALIA FROM THE SEISMIC DATA

A.G. Goncharov (AGSO, GPO Box 378, Canberra, ACT, 2601, Australia), M.D. Lizinsky (St.-Petersburg Mining Institute, 21 line, 2, St.-Petersburg, 199026, Russia), K.A.Kalnin (St.-Pb.MI), T.N. Fomin (AGSO), C.D.N. Collins (AGSO), B.R.G. Goleby (AGSO), B.J. Drummond (AGSO) and L.N. Platonenkova (St.-Pb.MI)

Commonly anomalously high velocity rocks in the Precambrian regions are underlain by anomalously low velocity rocks and vice-versa so that a balancing of high and low velocities can be seen along any vertical profile through the crust. The average seismic velocity-depth distribution gives an estimate of the degree of this balancing ("seismic isostasy") at any given depth. In the Baltic Shield and in the Mount Isa region (Australia) "seismic isostasy" is achieved well above the Moho. These results are based on the data collected by different seismic methods, including deep seismic sounding profiles, and vertical seismic profiling in the Kola Superdeep Bore Hole. If a single and unique velocity-density correlation exists, then "seismic isostasy" achieved at a certain depth will translate into conventional isostasy at that depth. Intra-crustal isostasy may exclude or reduce the need for isostatic equilibrium to be achieved at the Moho or lithosphere-asthenosphere boundary in Precambrian crust. Whatever the geological scenario explaining our observations, it must be consistent with a concept of mass transfer in Precambrian crust being a balanced process even in its local aspects. These results will have implications in studies of lithospheric deformation and can also be useful for modelling elastic properties of the crust from an assumed petrological composition or from a xenolith-derived composition.

LOW VELOCITY LAYERS, INTERFERENCE AND SEISMIC IMAGES OF THE PRECAMBRIAN UPPER CRUST

A.G. Goncharov (AGSO, GPO Box 378, Canberra, ACT, 2601, Australia)

Low velocity layers have been detected in many Precambrian regions by land seismic profiles. Vertical seismic profiling (VSP) in the Kola Super Deep Borehole gave a direct indication of the complicated seismic structure of the upper crust with numerous low-velocity layers of different scale down to a depth of 12 km. Constructive interference of numerous converted waves, multiples and peg-legs originating in the upper crustal model with low-velocity layers is a very important factor for the formation of the seismic image of the crust. Large offset seismic response remains remarkably stable regardless of a specific velocity structure within a large scale low velocity layer. At the same time it is very different from what can be expected from modelling of primary reflections only. These results may have implications in understanding of the nature of near horizontal regional boundaries detected by refraction/wide-angle investigations in many regions.

EFFECT OF DEFICIENCY AND INACCURACY OF EXPERIMENTAL DATA ON DSS RESULTS

T. Ilchenko, Institute of Geophysics of National Academy of Sciences of Ukraine, Kiev

Results of wide-angle deep seismic sounding (DSS) are restricted because of deficiency and inaccuracy of experimental data. The DEFICIENCY is mainly caused by descrete spacing of shotpoints. In consequence, an adequate way of modelling is formation of a total velocity (V) model from separate parts within each of which a V-distribution can be determined irrespectively of the others and usually from a pair of reciprocally correlated phases. Such refraction data constrain whether V-function is 1D or 2D, continuous or contains V-contrasts as well as a sign of the latter. But only a 1D, continuous V-function can be unequivocally evaluated. This task for the others requires additional data and/or assumptions (first of all, demand of the simplest result). A pair of correlated reflected phases does not provide enough data to distinguish even between 1D V-function with arbitrary reflector incline and 2D V-function with a horizontal reflector. In practice, the first type is used. INACCURACY of experimental data spreads a traveltime curve along time-axis, turning it from line into strip. Correspondingly, every parameter of the obtained V-model is characterised by an interval of values, limiting DSS potentialities to study medium heterogeneity.

ELASTIC CONSTANTS FROM AVO INVERSION

H. Kurt and E. Demirbağ (İstanbul Teknik Üniversitesi, Maden Fakültesi, Jeofizik Mühendisliği Bölümü, Ayazağa-80626, İstanbul, Turkey)

An inversion method is formulated to estimate the elastic constants of two elastic media seperated by a flat horizontal boundary, by using the P wave reflection amplitude versus offset (AVO) data. The Zoeppritz equations which describe seismic energy partitioning at a boundary is redefined with elastic constants which are bulk modulus (k), Poisson's ratios (σ), and densities (ρ) of the each layer. After redesigning the equations by these elastic constants, instead of P and S wave velocities, the reflection coefficient of P waves in the Zoeppritz equations, Rp, is calculated as a function of ratios of k and ρ of the lower layer to those of the upper layer (k_2/k_1 and ρ_2/ρ_1) and Poisson's ratios of the upper and lower layers (σ_1 and σ_2). In this inversion, the aim is to find these four parameters and to interprate the elastic properties of rocks, especially for the upper crust. Calculation of R_p and its derivatives with respect to elastic constants in the inversion is achieved analitically and this is an important advantage among the other AVO inversion methods which are based on numerical solutions or approximation of the Zoeppritz equations. Morever, another positive point is that using ratios of k and ρ instead of their seperate values improves the success of inversion because of the reduced number of inverted parameters.

ANALYSIS OF THE RESOLUTION OF THE TRAVEL TIME INVERSION

I.B. Morozov and S.B. Smithson (Dept. of Geology and Geophysics, University of Wyoming, Laramie, WY 82071-3006, USA)

Velocity/space trade-off is one of the major factors limiting the travel time inversion of wide-angle and deep seismic sounding data. We present techniques for the estimation of the resolution of velocity-interface models obtained using several types of the travel time inversion. We show that the resolution analysis does not need to be a part of the inversion technique, but may be implemented as a separate procedure. For a refraction/reflection travel time tomography, we discuss the resolution matrix technique and analyze the limitations imposed by the damping. For velocity models obtained using the conventional ray tracing, we examine their velocity/space resolution by the Monte-Carlo sampling of the parameter space and travel-time field ray tracing, followed by the factor analysis. Both techniques are applied to the analysis of the P-wave velocity models for the crust of the northeastern Eurasia obtained by the inversion of the seismic data from the ultra-long profile "Quartz".

INTEGRATED SEISMIC WIDE-ANGLE AND NORMAL INCIDENCE INTERPRETATION, MONA LISA LINE 3 ACROSS THE CENTRAL GRABEN, NORTH SEA

L. Nielsen, L. Klinkby, N. Balling and MONA LISA Working Group (Geophysical Laboratory, University of Aarhus, Finlandsgade 8, DK-8200 Aarhus N, Denmark)

The high-quality MONA LISA wide-angle recordings provide a unique data set for investigating detailed crustal velocity structure across the Central Graben, North Sea. Using ray tracing and inversion a detailed crustal velocity model has been derived from these data. Converting the P-wave velocity model to two-way travel time, a direct comparison was made of this model to the coincident near normal incidence data.
The combined interpretation of the wide-angle and normal incidence data shows pronounced crustal thinning (about 15 km) with associated MOHO uplift beneath the thick graben sediments. The velocity model of the crust shows significant lateral variations with respect to both crustal thickness and velocities. The crustal segments east and west of the Central Graben show different characteristics in terms of velocity structure and internal reflectivity/layering. Other detailed structures, such as sedimentary layers and the eastern boundary fault of the graben (Coffee Soil Fault), are constrained by the normal incidence data.

WIDE ANGLE REFLECTION MIGRATION, POSSIBILITY AND LIMITATION

Pilipenko V.N., Institute of Geophysics, Palladin 32, Kiev, Ukraine.

An attempt was made to apply the migration technique to the wide-angle reflection data obtained along the marine and land DSS profiles in the Baltic Shield. A new migration method developed for the refraction and wide-angle reflection data was applied. The method based on finite-difference solutions of the time and wave equations on the special grids. Two solutions are obtained independently: the time fields are calculated on 2-D space (depth-distance) grid, the wave fields - on 3-D space-time grid. The reflection time fields are continued from the point source to the grid points; the wave fields are continued from the surface where they were recorded into the medium and determined at a set of depth levels. A special transformation of the grids is used for different types of waves . The grid lines are curved and follow the rays and wave fronts. This increases accuracy of the wave field continuation and excludes the points where the wave equation solution can not be obtained. For large distances from the source and for inhomogeneous media the finite-difference solution of the eiconal equation is possible it it is found on the orthogonal grid formed from the seismic rays and isochrones at linear change of seismic velocities. The velocity gradients for the grid parameters are determined from the velocity model averaging. The seismic images of the crustal structure obtained from the migration for both profiles and for the P- and S- waves look realistic. There is a noise background formed by the migration 'smiles' but some specific features of the crust and of the Moho clearly observed. The results have shown the processing techniques, like the migration, can be used for the low-fold wave fields as the wide-angle reflection data however the observations should be more detailed to get more reliable results.

Phase-array decomposition of a seismic section.

Roland Roberts and Ari Tryggvason
Department of Geophysics, University of Uppsala, Villavagen 16, 752 36 Uppsala, Sweden.

A seismic refraction/wide-angle reflection profile is analysed for the presence of correlated events ("phases"). The correlation problem is formulated in terms of temporally, spatially, and frequency local complex covariances. For robustness, the method concentrates on phase rather than amplitude information. This allows a computationally efficient algorithm which can make allowance for signal correlation length and can model curved wavefronts. A statistical test based on residual phase misfit across the analysed sub-array is used to assess the probability that a detected event represents a real correlated signal. Using simple techniques based on one-dimensional Earth models, over 1000 detected events are associated with a small number of particular wave types and paths through the Earth.

HIGH-FREQUENCY WAVE PROPAGATION IN THE UPPERMOST MANTLE

T. Ryberg (GeoForschungsZentrum, Potsdam, Germany)
F. Wenzel (Geophysical Institute, Karlsruhe, Germany)

Short period, three component recordings of the seismic wavefield of Peaceful Nuclear Explosions (PNE's) on the QUARTZ profile are used to constrain the nature of the high-frequency teleseismic P_n phase, which can be observed for receiver distances of more than 3000 km. We suggest that this phase is caused by velocity fluctuations in the upper mantle acting as scatterers. To test this hypothesis and to model the coda of the high-frequency teleseismic P_n phase, its most prominent characteristic, numerical simulations of the wave's propagation using the elastic reflectivity method (one-dimensional models) were carried out. Both the QUARTZ data and the synthetic record sections were analyzed by examining the coda decay rates of the teleseismic P_n phase. Synthetic seismograms are computed for different models based on the global model IASPEI-91 with an added zone of randomly distributed velocity fluctuations (lamellae) just below the crust-mantle boundary. These models may be characterized by the thickness of the scattering layer, the heterogeneity correlation distance, a, and the heterogeneity standard deviation, σ. A comparison of the modeling results with the observations along the Quartz profile shows clearly that a velocity model containing velocity fluctuations in the upper mantle can easily explain the presence of a predominantly high-frequency teleseismic P_n coda.

SYSTEM ANALYSIS OF THE SOLUTIONS OF INVERSE SEISMIC PROBLEM

E.L.Shen and V.G.Kozlenko

Institute of Geophysics Nat. Acad. Sci., 32 Pr. Palladin, Kiev 252680, Ukraine

The solutions of inversion found by different authors give the divergence in the models. These divergences may reach considerable values. The problem of choicing an adequate solution (model) is arising. Special model parametrisation and systematization in the space of integral parameters of the model change the meaning of the posed problem. The criterium of quality of velocity models is *rms (Q)* between calculated and observed travel times. In addition, two integral parameters A and B, characterizing the anomalous structure of the model, are assigned to every model. In the space of Q, A,B parameters the models are presented by points. On the basis of test "California" it was determined that the obtained Q values correspond with function $Q=f(A,B)$, forming the global minimum. A greate number of solutions of inversion do not contradict, but supplement and confirm each other. Jointly they give the solution of probable meaning.

STRUCTURE OF THE DEEPER PARTS OF THE EARTH CRUST IN THE TERRITORY OF YUGOSLAVIA ON THE BASIS OF DSS DATA

Slobodan Stanić[1]
NIS-NAFTAGAS, Geophysical institute, Belgrade, Yugoslavia[1]
University of Belgrade, Faculty of mining and geology, Belgrade, Yugoslavia[1]

Significant amount of useful information on structure of the deepest parts of the Earth crust, in the territory of Yugoslavia, is obtained by data of four DSS profiles, transsecting SR Yugoslavia and adjacent countries. All DSS data analyses direct to conclusion that structure of the Earth crust of the territory is very complex, not only from geotectonic, but also from lythophysical viewpoint. This conclusion is verified on the basis of results of other geological and geophysical exploration. In the paper, structural model of the Earth crust of the territory of Yugoslavia obtained by comparative analysis of DSS data and other geological and geophysical results.

INTERPRETATION OF SEISMIC PROFILE LT-7 ACROSS THE TEISSEYRE-TORNQUIST ZONE IN NW POLAND - RESULTS FROM EUROPROBE SEISMIC WORKSHOPS

H. Thybo (Geological Institute, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark)
A. Guterch and M. Grad
(Institute of Geophysics, Polish Academy of Sciences, ul.Ksiecia Janusza 64, PL-01452 Warsaw; Poland)

The coincident seismic refraction and reflection lines LT-7 and GB-1 in NW Poland have been the subject of interpretations at two EUROPROBE workshops. The aim was to compare interpretation methods and to determine the crustal structure across the Teisseyre-Tornquist Zone (TTZ). Several processing approaches have been applied to the data set: Frequency analysis of seismic phases, Amplitude analysis, and DSS velocity filtering. Modelling approaches included: Ray tracing modelling, Traveltime inversion, Wavefield analysis, Reflectivity modelling, Wave TTC method, NMO correction of wide-angle reflections, and the LINKMOD algorithm. The resulting models from all the algorithms are similar. It was found that the main factor that affects the results of the interpretation is the phase correlation of the seismic sections. The interpretations show very low velocities below the Palaeozoic Platform (PP); clear structures from surficial inversion; different velocity structure between the PP and the East European Platform (EEP); and abrupt crustal thickening at the TTZ which, however, may extend into the EEP. The approaches to the interpretation and the resulting models will be described and compared.

PARAMETRIZED 3D ALPINE CRUSTAL STRUCTURE AND IMPLICATIONS FOR TELESEISMIC WAVEFRONTS

F. Waldhauser, E. Kissling, J. Ansorge (Institute of Geophysics, ETH Hoenggerberg, CH-8093 Zuerich, Switzerland)

Effects of complex 3D crustal structure on teleseismic traveltimes have long been neglected when investigating Alpine lithosphere by teleseismic tomography. Wavefront deformation at the crust-mantle boundary strongly influences teleseismic traveltime residuals. In order to quantify this effect, we developed a 3D velocity model of the crust and uppermost mantle of greater Alpine region, using data from the dense network of controlled-source seismic profiles. The 3D model parametrization scheme accounts for main structures such as the crust-mantle discontinuity and low-velocity sedimentary basins. In particular, possible strategies for further refinement and/or updating the 3D model are outlined and tested. Teleseismic wavefront geometries for the strongly heterogeneous 3D-velocity model are calculated with a finite difference solution to the 3D-eikonal equation. First arrival times from a selected number of different source locations are traced through the 3D model documenting the effect of deep crustal structure by the migration of local traveltime anomalies at the surface in relation to azimuth of incoming waves. First results from a comparison of calculated and real data across the Alpine orogen are shown.

RAYLEIGH WAVE-SCOPY OF THE SOUTH CASPIAN LITHOSPHERE

A.N. Yacobson, JIPE RAS, B.Gruzinskaya 10, 123810 Moscow, Russia

The detailed seismic R- wave tomography for the first time applied for the lithosphere investigation under the S. Caspian basin combining velocity dispersion and wave scattering usage was named Rayleigh wave-scopy (RWS).From the wave velocity space distribution by inversion at proper points they get a set of the shear wave velocity columns. Some blocks-scatterers may be roughly delineated by using of scattered R-wave energy. Under the cover of sediments the graben is discovered. The rocks with the mantle velocities of 4.6km/s and more come out to the base of sediments predominantly under the graben. The low-velocity layer is found out almost everywhere in the region under the top of the basement.The "granite" velocities are seen under the shores and as the separated patches under the aquatory (as probable remnants).The narrow linear zones of lowered velocities are found out connected to parts of some faults.Mud volcanoes are situated predominantly above the areas of the minimal velocity in the low-velocity layer; the prognostic sign of deep hydrocarbon accumulations is defined in this connection.

SE12/G13 Earth rotation and its interaction with other geophysical phenomena

Convener: Kolaczek, B.
Co-Conveners: Dehant, V.; Hinderer, J.; Schuh, H.

Long-periodic variations of the Earth's rotation and geopotential

Yu.V.Barkin (Astronomical Institute, MSU, Univ. pr-t, 13, 119899, Moscow)

Slow and considarable redistributions take place no only in external Earth's cover, but in its inner covers. Geophysical and tectonic processes in the external cover are studied for many years. To inner processes in first we refer: rigid core (RC) motions, slow changes of the MCB, inhomogeneities motion relatively liquid core. In given report the model of the long-periodic motion of the RC are suggested for explanation of the set observed geodynamical phenomena. Variations of the geopotential and Earth's rotation caused by RC motion are defined. In some approximation the RC oscillates along geocentric axis oriented to North Atlantic with period 3000 years about some average position of the RC mass center displaced from geocenter along this axis on 5-10 km in north direction. Amplitude of oscillations reaches 10-15 km. Suggested model of the RC motion in general explains: 1) long-periodic variation of the dayly rotation of the Earth with period 1500 years (Morrison, Stephenson, 1995); 2) secular geocenter motion in south direction (Montag et.al., 1995); 3) gravity variations in Australia, in Europe and in other regions of the Earth. Particularities of the RC motion are in agree: 4) with data about topography of the outer core (Morelli, Dziewonski, 1985); 5) with constant displacement of the inner core caused by attraction of the inhomogeneities on the MCB (Barkin, 1995); 6) with model of the Earth PREM (Dzienowski, Anderson, 1985); 7) with values of tidal and nontidal accelerations of the Earth (Morrison, Stephenson, 1985); 9) with data about westdrift and change of the magnetic field and other.

TEMPORAL VARIATIONS OF THE AMPLITUDES OF THE NUTATIONS AND DIURNAL ATMOSPHERIC FORCING

Ch. Bizouard (Observatoire de Paris, 61 avenue de l'Observatoire, 75014 Paris, France, e-mail : bizouard@obspm.fr)

Analyses of the celestial pole offsets (estimated from VLBI and optic data) have exhibited significant variations of the amplitudes of the main nutations. We attempt to find correlations between these variations and these of the Earth-atmospheric diurnal coupling.

PRECISION OF A PRECESSION-NUTATION AND ROTATION SOLUTION FOR A RIGID EARTH

P. Bretagnon (Bureau des longitudes, 77 avenue Denfert-Rochereau, 75014 Paris, France)

We present a solution of the rigid Earth rotation in which the diurnal and semidiurnal terms coming from the tesseral harmonics have been calculated with a high precision. These perturbations, that one ought not to impute to geophysical origins, reach in the time domain 150 μas in the nutation in longitude, 60 μas in the nutation in obliquity and 140 μas for the rotation of the Earth. For the zonal and tesseral harmonics taken into account, the complete solution has a precision ranging about 1 μas, precision become necessary by the quality of the VLBI observations which give the orientation of the Earth at the level of 20 μas.

TIDES AND EARTH ROTATION

P. Brosche (Observatorium Hoher List, D-54550 Daun, Germany)

The three major components of the Earth (solid part, oceans, atmosphere) are subject to tidal forces from Moon and Sun. Their interactions with the tide-generating bodies and amongst each other cause transfers of angular momentum and energy. We describe the achievements and the problems in the theoretical understanding of the balance. The theoretical predictions are confronted with the observations of the rotation of the solid Earth. Those data should be augmented by observations of the concomitant changes in the lunar orbit. The latter are especially important for the secular effect of tidal friction in the Earth-Moon-system.

NEW ESTIMATION OF THE FREE CORE NUTATION PARAMETERS

A. Brzeziński and S. D. Petrov (Space Research Centre, Polish Academy of Sciences, Bartycka 18A, PL-00-716 Warszawa, Poland)

Recently, there have been several attempts to estimate the free core nutation (FCN) parameters, the period of resonance T and the quality factor Q, from the VLBI nutation observations and/or the tidal gravimetric data. The standard approach, based on the resonant enhancement of the amplitudes of the lunisolar nutations and the tidal gravity waves, yields consistently 430 to 435 days for the FCN period, that is about 30 days less than predicted by the theory assuming hydrostatic equilibrium, and different values for Q, ranging from about 3000 up to 30000. An alternative method which consists in tracking the freely excited variable FCN signal in the celestial motion of the pole observed by VLBI, gives significantly different estimates: about 418 days for T and 55000 for Q (Brzeziński, 1996). We consider here an extension of the last algorithm by incorporating into the analysis available estimates of the atmospheric/oceanic excitation function. It is expected that this approach can help us to constrain more reliably the FCN parameters and explain large discrepancies between aforementioned estimates.

A SUPERFLUID HELIUM GYROSCOPE

S. Burkhart, A. Friesch, F. Hasselbach (Institut für Angewandte Physik der Universität Tübingen)
H. Ruder (Institut für Theoretische Astrophysik der Universität Tübingen)

We present an experiment, the final purpose of which is to detect deviations in the earth rotation rate.
The device is a SHEG (Superfluid Helium Gyroscope) and is based on superfluid phase interferometry. A pressure is applied to a superfluid which flows, under the corresponding phase difference, through an orifice in a loop. Above a critical phase difference quantum vortices nucleate and remove energy from the friction free potential flow. This critical phase can be offset, within the loop, by rotation. A first successful attempt to measure rotation by detecting this offset was performed by the Avenel and Varoquaux group in Saclay CEA (France) who measured the earth rotation with a precision of $10^{-2}\Omega_E$.

REVIEW OF THE SITUATION FOR THEORETICAL NUTATIONS OF A NON-RIGID EARTH AND COMPARISON WITH THE OBSERVATIONS

V. Dehant (Royal Observatoiry of Belgium, 3 avenue Circulaire, B-1180 Brussels, Belgium)

In 1980, the IAU has adopted a theoretical nutation series based on Kinoshita-1977 rigid Earth nutation series and on Wahr-1981 transfer function for an ellipsoidal rotating deformable Earth with an elastic inner core, a liquid outer core and an elastic mantle. In 1994, the IAU has realized that this theoretical series is not sufficient for practical users and has adopted an empirical model based on parameters determined from VLBI observations by Herring. This paper reviews the situation and presents the results of a new theoretical nutation series computed by Dehant and Defraigne, for Wahr's model completed (1) by mantle inelasticity, and (2) violation of hydrostatic equilibrium for the Earth's initial state, and (3) for new rigid Earth nutation series as the one recently computed by Souchay and Kinoshita or the one of Roosbeek and Dehant. Finally we will compare the new theoretical values with the observations deduced from VLBI data.

TAKING INTO CONSIDERATION GEOPHYSICAL FACTORS WHILE INTERPRETING VARIATIONS OF THE EARTH FIELD GRAVITATION

P.D. Dvulit (State University "Lviv Politechnic", S. Bandera Street 12, 290646, Lviv, Ukraine)

Determination of the time changes of the points' position of the Earth's surface and a derivative of the field of gravitational is the main task of fundamental geodynamic studies. Repeated measurements of the gravity at the points of a high precision global network make it possible to estimate position of the Earth centre masses in relation to some global system of co-ordinates and to measure variations of the field of gravitation. During the interpretation of the variations of the Earth's field of gravitation one should take into account influence of various geophysicalfactors. Among them we draw attention to the influence of atmospheric processes (redistribution of air masses, availability of snow cover), hydrological regime (change of ground waters' level), woodiness (seasonal changes of the ground part of forest mass), etc. Applying methods, which we worked out, influence of every geophysical factor on gravity, deformation of a surface level, and components of the vertical deflections has been evaluated for different points of the global network. It has been shown that the above-mentioned geophysical factors influence differently derivatives of the gravity field, absolute values of which correspond to the order of several microgal, several centimetres, and several ten-thousand's parts of an arc second. Taking into account the fact that the aforesaid influence can be 5-10 times higher than precision of modern measurements, certain recommendations concerning study of the variations of the gravity field and their influence on the Earth's rotation have been given.

ANALYSIS AND COMBINATION OF LENGTH OF DAY SERIES DERIVED FROM VARIOUS TECHNIQUES

Laura I. Fernandez (Fac de Astronomicas y Geofisicas Universidad Nacional de La Plata, Argentina)
Daniel Gambis (International Earth Rotation Service, Paris Observatory, 61 avenue de l'Observatoire, Paris, France)

Length-of-day (LOD) independent series derived from various techniques (Lunar Laser Ranging, Very Long Baseline Interferometry and Global Positioning System) have been statistically analized over a time span of about 2 years. The objective is to perform an optimal combined LOD solution whereas LOD series are generally derived from Universal Time. After removing systematic fluctuations, the external agreement for the combined series has been studied using estimated weight factors from the difference between each series and LOD combinated serie C04 from the International Earth Rotation Service (IERS). The performance and assessed quality of this combined series with respect to (IERS)C04 LOD series is presented.

OPPOLZER'S TERMS FOR A NON RIGID EARTH

V. Frede (Observatoire de Paris, 61 avenue de l'Observatoire , 75014 Paris, France)
V. Dehant (Observatoire Royal de Belgique, avenue circulaire 3, 1180 Bruxelles, Belgium)

We define the Oppolzer's terms of any axis GX, as the part corresponding to the long period motions as expressed in space, of the offset forced by gravitationnel tides between this axis and Gz (Gz is the third axis of the terrestrial frame).
We examined two different approaches to determine the Oppolzer's terms for a non rigid Earth as it has never been done before.
On the one hand, we applied the angular momentum conservation theory to express analytically the Oppolzer's terms as a fonction of the inertial increments and the deformations caused by non rigidity.
On the other hand, we used Wahr's transfert function between nutations of the non rigid Earth and nutations of the rigid Earth.
We have obtained very consistent results for the values of the Oppolzer's terms for the angular momentum axis and for the rotation axis calculated for each main nutation frequency.

ATMOSPHERIC EXCITATION OF THE FREE AND FORCED NUTATIONAL MOTION OF THE EA RTH

P. Gegout and J. Hinderer, H. Legros, M. Greff (Ecole et Observatoire de Physique du Globe, Strasbourg, France)
V. Dehant (Observatoire Royal de Belgique, Bruxelles, Belgique)

This study is devoted to the excitation of the Earth's rotational motion of diur nal period by global atmospheric pressure changes. We address the problem of the nutational motion and focus on the amplitude of the Free Core Nutation which ha s been observed recently in VLBI measurements. We compute the atmospheric pressure torque over the Earth's topography from a global pressure field (1.125° by 1.125° data sampled every 6 hour) provided by the European Centre for Medium Range Weather F orecasts (ECMWF). The response of the oceans to pressure excitation is approximated by the static ocean model which is different from the non-inverted barometer (NIBO) and the inverted barometer (IBO) hypotheses and depends on the degree of the spherical harmonic decomposition of the pressure field. The most efficient term in perturbing the nutations is the S_1 solar barometric tide of thermal origin which exhibits st rong seasonal modulations. We point out the importance of atmospheric pressure effects with re spect to gravitational effects of lunisolar origin. We also estimate the excita tion power available from the pressure torque to explain the mean observed FCN amplitude. It is suggested that the atmospheric pressure is a good candidate for randomly exciting this free rotational mode.

VLBI DETERMINATION OF EOP: ACCURACY AND PRECISION OF RESULTS.

J. M. Gipson (NVI Inc/GSFC, Greenbelt, MD, USA)
C. Ma (GSFC, Greenbelt, MD, USA)

VLBI measurements have historically provided the most accurate and precise measurement of UT1, Polar Motion, and nuation/precession. Recently GPS has begun producing estimates of Polar Motion with precision comparable to that of GPS. VLBI remains unique in its ability to measure UT1 and nutation/precession. These measurements have led to improved understanding of the dynamics of the earth. The formal errors on daily estimates from the best VLBI experiments is 2 ms for UT1, 70 ms for Polar Motion, 160 mas for nutation longitude, and 60 mas for nutation obliquity. It is possible to estimate EOP variation at intervals as short as 1 hour using VLBI data. The formal errors for hourly estimates of EOP are 8 ms for UT1, and 200 mas for PM. Comparison of simultaneous EOP measurements from different networks indicates that the formal errors need to be inflated by 50%. This is indicative of sources of unmodeled error. We describe these sources, estimate their magnitudes, and give prescriptions for reducing these errors.

PRESENT ACCURACY OF EOP AND ANALYSES OF INTERACTION BETWEEN GEOPHYSICAL PHENOMENA AND EARTH ROTATION

D. Gambis (International Earth Rotation Service, Paris Observatory, 61 avenue de l'Observatoire, Paris, France)

The determination of the Earth Orientation Parameters is now principally based on SLR, VLBI and GPS techniques. The contribution of these 3 techniques is essential from the point of view of their complementarity but also for some aspects linked to redundancy. The intercomparisons of the various EOP series allow the characterization and estimation of their systematic content. Thus, the combination of these series which is performed at IERS/BC takes advantage of the accuracy of the different series at the various time scales. This enable the investigation of various geophysical phenomena which were not detectable in the past. Various phenomena linked to geophysics are perturbing the Earth Rotation on time scales ranging from a few hours to centuries and their understandings require accurate, extended and continuous determination of EOP series.
The presentation describes the metrological aspects linked to the combination of Earth orientation parameters and give some exemples to illustrate how analyses of the EOP series can help geophysicists to understand the global Earth dynamics.

ON THE EXPEDIENCY OF ORGANISATION OF JOINT ASTRONOMICAL AND GEOPHYSICAL OBSERVATIONS IN THE DEEP VERTICAL PITS

A.Gozhy (Poltava Gravimetrical Observatory,
Myasoyedova Str. 27/29, 314029 Poltava, Ukraine)

The study of changes of gravity value and plumb line with combined astronomical and geophysical techniques is of exeptionally great significance for geophysical hypotheses verification, for investigation of the earthquake nature, forecasting the latter. It is hardly possible to combine high precision geophysical observation of the gravity direction changes with the astronomical ones at the currently available stations of long-term astronomical observation because the former are carried out in the deep underground chambers and the latter are conducted on the ground surface. It can be remedied by organising both astronomical and geophysical observations in the deep vertical pit. In such a case the geophysical observations may be conducted by the traditional techniques and means whereas the astronomical ones - by means of special instruments, such as the photoelectric zenith tube, the pendulum type astrolabe, the optical star interferometer. Provided the observation of the gravity force value is organised in such a pit it may be possible to determine all algebraic combinations of Love's numbers at one and the same station of observation. These joint observations are of special interest for geodynamics.

THE INFLUENCE OF GRAVITATIONAL CORE-MANTLE COUPLING ON THE EARTH'S ROTATION

M. Greff and H. Legros (Ecole et Observatoire de Physique du Globe, 5 rue Descartes, 67084 Strasbourg Cedex, France)

The rotation's theory of the fluid core of the Earth fundamentaly depends on the pressure coupling at the Core-Mantle boundary. Still we know that a discrepency exist between the predicted and observed values of the nearly diurnal frequency. We can figure whether the rotational or magnetic features of the core provide it some elasticity and therefore a partial rigidification; or that a differential axial rotation inside the core splits the equipotential surfaces from the equidensity surfaces. These departures to the hydrostatic equilibrium can also be seen as density anomalies inside the core's structure. Whatever the origin of the density anomalies, when the core is oscillating, the attraction of the mantle exert a gravitational torque upon the core. Using the theorem of angular momentum, we study the rotation of the core when it is moreover submitted to this gravitational torque. The main result of the theory is the existence of a new eigenfrequency : because the core is partially rigid, it has three rotational eigenmodes, the axi al mode, the nearly diurnal mode and a new mode which is similar to the chandler mode of the mantle. Under the hypothesis of a partial rigidification of 19 percents, we find a diffe rence between the sideral frequency and the nearly diurnal eigenfrequency to be $\Omega/438$, which is close to the observed value; and the period of the new eigenmode is 19.6 years.

DECADE VARIATIONS OF LOD: ATMOSPHERIC EXCITATION AND CORE-MANTLE COUPLING

H. Greiner-Mai (GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany)

Recent investigations have shown that time series of the length of day (LOD) contain periods which correspond to periods that are identified in the atmospheric excitation function derived from air pressure variations by using the geostrophic approximation. Here, we continue the investigation by improving the data processing. We show that for the periods of about 35 and 75 years the theoretical amplitudes are not large enough to explain the observed periods in LOD. By contrast, the solar periods of about 11 and 22 years are totally excited by atmospheric processes. The longer periods can also be identified in the geomagnetic field variations and therefore suggest an excitation via core-mantle coupling. However, recent models of the electromagnetic core-mantle coupling can explain the observations only if the electrical conductivity adopted for the lower mantle is very high. Reducing the observed variation of LOD by the part excited atmospherically, we obtain long-period length of day variations that are fully associated with the variation of geomagnetic quantities. The re-examination of the core-mantle coupling torques then shows that the lower-mantle electrical conductivity reduces towards more reasonable values. Finally, as an outlook on possible future investigations, we discuss some empirical correlations between variations of geomagnetic and climatic quantities.

THE EARTHQUAKE AND EARTH's ROTATION

Z.N.Gu(Shanghai Observatory, Academic Sinica, Shanghai 200030, China)

Using the fault plane parameters, the location of epicenter and the expression given by Dahlen as well as the step function, the accumulative change of both the axial and the equatorial moments of inertia of the Earth induced by earthquakes (EQ) occurring in period of 1977–1994 is estimated in this paper. Results have shown that the change of pole axis direction induced by single EQ is independent of the magnitude of EQ. The EQ tends to make the rotational pole drift towards the direction of $130 - 150^0$ E. This direction is roughly different to that inferred from observations. The change depends upon the slip angle of the fault movement in a large extent. The polar motion (PM)and the length of day (LOD) excited by EQ are at least two orders of magnitude less than those derived from observation. In the future with high observational accuracy the effect of EQ on PM and LOD would be observable.

MECHANISM OF THE NON-TIDAL VARIATION OF THE EARTH ROTATION– INTERACTION BETWEEN THE SOLAR WIND AND THE MAGNETOSPHERE

Z.N.Gu., G.X.Song., W.J.Jin (Shanghai Observatory, Academic Sinica, Shanghai 200030, China)

The long period variation of the Earth Rotation is generally explained by the tidal friction. In terms of the historical records of the solar and lunar eclipses as well as the study of the growth line of corals, a lapse rate of -2.4ms/cy in LOD was documented. The tidal friction, however, is not the only source to influence the Earth rotation. Non-tidal factors are required to describe the extra long term variation with 1ms/cy. By means of the interaction between the solar wind and the magnetosphere, a phenomenon of the moving magnetic lines of the Earth from the co-rotation with the Earth to the non-corotation in the region of the magnetic tail will introduce a shear stress in the direction of the longitude, which could be considered as a source of effecting the long term variation of the Earth rotation. It is shown in this paper that this mechanism can produce an angular deceralation of the Earth rotation in the magnitude of $\dot{\Omega} = -3.2\times10^{-23}/s^2$. This result might be a prompt to search other sources of the long terms in the Earth rotation variations further.

INTERNATIONAL RADIO INTERFEROMETRIC SURVEYING - SOUTH: EARTH RO TATION RESULTS

R. Haas, A. Nothnagel (both at Geodetic Institute of the University of Bonn (GIUB), Nußallee 17, 53115 Bonn, Germany)
G. Nicolson (Hartebeesthoek Radio Astronomical Observatory, South Africa)

Since December 1989 the IRIS-S (International Radio Interferometric Surveying - South) network has been scheduled in monthly intervals. After several changes in the network configuration the standard IRIS-S network consists of four stations today, i.e. Westford Observatory (Massachusetts, USA), Wettzell Geodetic Fundamental Station (Bavaria, Federal Republic of Germany), Hartebeesthoek Radio Astronomy Observatory (South Africa) and the station of Fortaleza in Brazil which adds a fourth station on a fourth continent.
In this talk we present results for the Earth Rotation parameters from this VLBI data set. Special consideration is put upon high frequency Earth variations which are compared with recent theoretical predictions. The importance of accurate modeling of Earth deformation effects for the determination of Earth rotation parameters will be addressed.

TOROSPHERE–POLOSPHERE INTERACTIONS AND TOPOGRAPHIC CORE–MANTLE COUPLING

R.Hide (Dept. of Physics, University, Oxford OX1 3PU, England, U.K.)

If the electrical conductivity of the lower mantle is much less than that of the underlying liquid metallic outer core, and the geodynamo is not confined to a thin boundary layer just below the core-mantle boundary (CMB), then the toroidal part of the geomagnetic field in the outer reaches of the core – the "polosphere" – will be no stronger there than the poloidal part. The dynamic pressure field associated with polospheric motions would be in "quasi-geostrophic" balance nearly everywhere with Coriolis forces, with the action of this pressure field on irregularities in the shape of the CMB producing a fluctuating "topographic" torque" $\boldsymbol{L}$ on the mantle, thereby making a significant and possibly even dominant contribution to observed decadal changes in the Earth's rotation (*Nature* **222**, 1055, 1969; *GRL* **22**, 961 and 3563, 1995). In the recent literature misunderstandings have arisen concerning the dependence of $\boldsymbol{L}$ on the magnetic field well below the CMB, particularly in the "torosphere". There, by definition, the toroidal part of the geomagnetic field is much stronger than the poloidal part, and concomitant Lorentz forces give rise to substantial departures from geostrophic balance in torospheric flow. Only in the (unlikely) absence of dynamical interactions between these two regions would $\boldsymbol{L}$ be unaffected by the geomagnetic field at depth within the core.

TORSIONAL MAGNETOHYDRODYNAMIC OSCILLATIONS OF THE EARTH'S LIQUID METALLIC CORE

R.Hide (Department of Physics, University, Oxford OX1 3PU, England, U.K.)
D.H.Boggs & J.O.Dickey (J.P.L., Pasadena, California 91109, U.S.A.)

Torsional oscillations of the Earth's core have been investigated by dividing the core into twenty imaginary equi-volume annuli coaxial with the axis of rotation of the Earth and determining temporal fluctuations in the axial component of angular momentum of each annulus, under the assumption that spatial variations of azimuthal motions in the core in the axial direction are negligibly small. The interval covered --1840 to 1980-- by the available velocity data (derived from geomagnetic secular variation data) is much shorter than the expected periods of *non-axisymmetric* magnetohydrodynamic (MHD) oscillations of the core, which are slowed down by Coriolis forces, but it is longer than the expected periods of *axisymmetric* torsional MHD oscillations, which are unaffected by Coriolis forces and depend mainly on B defined as the average over the core of strength of the non-axial component of the poloidal part of the geomagnetic field. The dominant period seen in the oscillations is about 60 years, and if this is that of the gravest mode, then the implied value of B is 0.0002T. This is no more than half the average strength of the geomagnetic field in the lower reaches of the mantle, and about two percent of the likely average strength of the *toroidal* part of the geomagnetic field within the core. Mid-latitude core angular momentum fluctuations correlate fairly well with angular momentum exchange between the core and mantle that is implied by observed fluctuations in the length of the day on decadal timescales.

SEASONAL VARIATIONS IN LENGTH-OF-DAY AND ATMOSPHERIC-ANGULAR-MOMENTUM

Joachim Höpfner (GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany; e-mail: ho@gfz-potsdam.de)

In this study, the following series of Length-Of-Day (LOD) and Atmospheric-Angular-Momentum (AAM) data at one-day intervals have been used: EOP (IERS) C04 from 1962 to 1996, AAM (NMC) from 1976 to 1995 and AAM (JMA) from 1983 to 1995. First, the seasonal oscillations are separated by filtering from the different time series. To illustrate their characteristics, the amplitudes, periods and phases of the annual and semiannual oscillations are then derived in their temporal variability. The discrepancies between the quantities of the annual and semiannual components of LOD-Sa as well as LOD-Ssa and χ_3(W), χ_3(W)+χ_3(P) as well as χ_3(W)+χ_3(P+IB) show to which extent uncertainties are present in the data, which portions of AAM originate from χ_3(W), χ_3(P) and χ_3(P+IB), and whether another excitation source contributes to seasonal LOD variations. At the annual frequency, a contribution from the global surface water redistribution is evidently responsible for the imbalance between the LOD and AAM data. However, at the semiannual frequency, the discrepancy is not fully explained by the surface water, and a contribution from a different excitation source is likely.

Relations of Interannual Variations of the Atmospheric Angular Momentum with Observed Ozone Trends

Evgeny A. Jadin

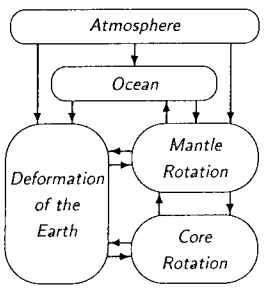
Central Aerological Observatory, Dolgoprudny,
3 Pervomayskay Str., 141700, Russia

The monthly mean anomalies of the stratospheric angular momentum (SAM), determined as the atmospheric angular momentum (AAM) from 100 hPa to 0.4 hPa, and total ozone are calculated using the NMC/CAC and TOMS data for 1979-1991. The strong negative correlations are found between the SAM and total ozone anomalies in the middle to high latitudes in winter/spring seasons. Together with the earlier revealed abrupt transition of stratospheric circulation to a new regime in summer 1980 (Jadin, 1996) this link can imply that observed ozone trends including the development of ozone hole in the Antarctic, are primary caused by decadal natural changes of atmospheric wave activity, which created favorable dynamical conditions for a chemical destruction of ozone layer. It is shown that the long - term propagation of the SAM anomalies resembles the V - structure (Dickey et al. 1992) of the tropospheric momentum propagation with the generation of disturbunces near equator, which are propagating to polar regions during a few years in winter-spring seasons. A possible method of empirical predictions of the future ozone layer behavior is proposed. In particular the large easterlies generated near equator in 1991/92 may result in a recovery of ozone hole in the Antarctic beginning from 1996 - 1998.

A MODULAR SYSTEM MODEL FOR A ROTATING EARTH

H.-U. Jüttner and H.-P. Plag (Institut für Geophysik, Christian-Albrechts-Universität zu Kiel, Olshausenstr. 40, D-24118 Kiel, Germany)

Models for Earth rotation perturbations most often are based on a system of differential equations, such as the Euler-Liouville equations, describing the rotational properties of the model. This approach requires a number of assumptions and simplifications in order to keep the equations treatable. Moreover, sophistications of the model generally require substantial changes of the equations. In a modular approach, the Earth system is represented by a number of subsystems interacting with each other both by boundary conditions and far-field interactions. This approach allows for successive sophistications inside each of the subsystems without requiring any changes in the other subsystem. We have set up an initial modular model for a rotating Earth comprising the subsystems and interactions displayed above. In the current version, the core rotates homogeneously, the ocean is equilibrium, and no magnetic field is included. Emerging properties of the current model including the eigenfrequencies will be discussed in their dependence on system parameters. The next steps of sophistication particularly in the treatment of the deformations in mantle and core will be outlined.



EARTH ROTATION AND THE CORE: EXPLAINING DECADAL VARIATIONS IN THE LENGTH OF DAY BY ELECTROMAGNETIC CORE-MANTLE COUPLING

R. Holme and K. A. Whaler (Department of Geology and Geophysics, University of Edinburgh, Edinburgh, Scotland, EH9 3JW)
J. Bloxham and W. Kuang (Department of Earth and Planetary Science, Harvard University, Cambridge, MA 02138, USA.)

Measured changes in the Earth's length of day on a decadal time scale are usually attributed to the exchange of angular momentum between the solid mantle and fluid core. One of several possible mechanisms for this exchange is electromagnetic coupling between the core and a weakly conducting mantle. The torque may be calculated from models of the conductivity of the mantle and flow at the top of the core. Unfortunately, the determination of the flow (from magnetic secular variation) is non-unique, and it is precisely that part of the flow that is unconstrained by the data which generates the most significant contribution to the electromagnetic torque. By solving an inverse problem for the flow, we demonstrate that reasonable core flows exist for 1900 to 1980 which explain both the magnetic secular variation and the observed changes in Earth rotation by electromagnetic coupling.
Of course, this does not demonstrate that electromagnetic core-mantle coupling really does account for the decadal variation in length of day. Recent numerical simulations of the geodynamo incorporate electromagnetic core-mantle coupling: we examine the solutions generated by one such model for clues as to how the coupling may act in the Earth.

WATER STORAGE AND POLAR MOTION

H. Jochmann (GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany)

Water storage excitation of polar motion is subject to many discussions in literature. These are caused by the fact that the amplitude of the annual wobble of polar motion is sufficiently explained by the atmospheric excitation, but, a phase delay between the annual periods derived from polar motion and atmospheric excitation suggests the existence of another excitation process. It is difficult to calculate the influence of water storage on polar motion, because the observations of ground water dephts are not well distributed at the earth's surface. Therefore precipitation was chosen as a parameter of water storage. As no global distributed data are available on evaporation, runoff, and the storage time of that part of precipitation flowing into the ground, a relation between water storage and precipitation was estimated using inverse solution. For this procedure it was supposed that the difference between the total excitation function of the annual wobble of polar motion and its atmospheric part is caused by water storage. Comparing this hypothetical excitation function with a pseudo-excitation derived from the precipitation load, it was found that water storage can be related to precipitation by a function containing two coefficients which are approximately constant at the earth's surface.

TIDALLY INDUCED SAGNAC SIGNAL IN A RING LASER

V. Rautenberg, **H.-U. Jüttner** and H.-P. Plag (Institut für Geophysik, Christian-Albrechts-Universität zu Kiel, Olshausenstr. 40, D-24118 Kiel, Germany)
M. Burns and G. E. Stedman (Dept. of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand)

A locally stationary ring laser senses the Sagnac effect, i.e. a beat frequency f between counterpropagating electromagnetic beams, with the beat frequency depending on the projection of the local rotation vector onto the area vector of the ring laser plane and the area and perimeter of the ring. Based on this Sagnac effect, high precision short-term observations of the projection of the Earth rotation $\mathbf{\Omega}_E$ on the area vector $\mathbf{A}$ of a ring laser are now possible. In principle, deformations of the Earth's surface alter the local vertical (tilt) and thus the direction of the normal vector of the ring laser. Additionally, the vorticity of the deformation is superimposed on the Earth's rotation. Finally, the deformations and associated gravity perturbations change the area and the perimeter of the ring laser. In our analysis, we estimate quantitatively the effect of the Earth's body tide deformations due to vorticity and tilt. Both terms are found to be latitude-dependent. At mid-latitudes, the vorticity $\delta\Omega$ is of the order $8 \cdot 10^{-8}\,\Omega_E$. However, being in the local horizontal plane, it is not detectable by a horizontal ring but will effect all other rings. For a horizontal ring at mid-latitudes, the Sagnac effect due to tidal changes in the normal vector is of the order of $4 \cdot 10^{-8}\,\Omega_E$ and should be detectable by the present or next generation of ring lasers.

NATURE EARTH'S MOTION OF POLE (CHANDLER'S MOTION)

Georges V. KIRIAN (The Main Astronomical Observatory of the Academy of Sciences, Jaque Duklo 12, apt. 2, 194223 St.Petersburg, RUSSIA)

To problem of a nature of Chandler's movement or Earth's instant pole of rotation is already more than 100 years. Not one generations of the scientists received it in the inheritance from the predecessors. Despite the first class works and number of brilliant names (Von Oppolzer T., Newcomb S., Tisserand F., Love A., Jeffreys H., Melchior P., Orloff A., Munk W., Rudnick P.,...), the problem and was not solved. At the same time importance and the significance of the decision of this problem is in due course increased. Present work demonstrates our study of the observant data (coordinate of Earth's instant pole for 1846-1990), several generations accumulated by transactionses of the scientists. The program and technique of researches were formulated by us in 1988-1989. At finished first stage of researches a physical nature of Chandler's movement (mechanism of excitation and maintenance of oscillations) is established cause-effect connections of movement of Earth's instant pole with the material world surrounding the Earth.

VARIATIONS OF THE INTENSITY OF SIBERIAN ANTICYCLONE AND EARTH ROTATION

A. A. Korsun' (Main Astronomical Observatory, National Academy of Sciences, 252650 Kyiv-22, Ukraine)

Variations of the Earth rotation, of the intensity of Siberian anticyclone and El-Niño Southern Oscillation over 100 years (from 1890-1990) are investigated. The power spectra frequency characteristics for these phenomena are shown to coincide closely. The relationship between the variations of intensity of Siberian anticyclone, El-Niño Southern Oscillation and Earth rotation variations are discussed.

STATISTICAL CORRELATIONS BETWEEN 10-YEAR VARIATIONS OF THE INTERANNUAL DATA OF SOME GEODYNAMICAL, GEOPHYSICAL, AND HELIOPHYSICAL PARAMETERS

A. A. Korsun' (Main Astronomical Observatory, National Academy of Sciences, 252650 Kyiv-22, Ukraine)
G. S. Kurbasova, (Simeiz Astronomical Observatory, 334242, Crimea, Ukraine)

Variations with the period $T = 10.4 \pm 0.3$ yr were filtered from interannual data of the following time series (1900-1990): Earth's polar coordinates, variations of length of the day, El-Niño Southern Oscillation, Earth's seismic energy, solar activity. The aim of this work is to compare the 10-year variations of different processes by the method of coherence analysis. The relationship between the terrestrial phenomena as well as possible reasons for coincidence of solar activity cycles with these phenomena are discussed.

A MECHANISM OF THE RELATION OF THE EARTH'S ROTATION TO DIFFERENT GEOPHYSICAL PHENOMENA

P.F.Krymsky (Institute of Cosmophysical Research and Aeronomy, 31 Lenin Ave., 677891 Yakutsk, Russia)

A transfer mechanism of the angular momentum from solar wind to the Earth [Geomagnetism i Aeronomiya. 1993. V.33, N3. S.7] rotates the atmosphere around the Earth from the west to the east. The interaction of the atmosphere with the Earth's surface creates the following phenomena:
-causes to move the lithospheric plates and generates the earthquakes;
-transfers the energy for the generation of the geomagnetic field and creates the west drift of the field;
-changes the Earth's rotation rate and creates the relation between these phenomena.
The geomagnetic field inversions create the catastrophic terrestrial phenomena.

Nonlinear effects in liquid core motion

O. KUDLAY (Main Astronomical Observatory of National Academy of Scienses , Kyiv , Ukraine)

The nonlinear effects influence on the liquid outer core motion is studied . Possible perturbations of the rotation axis trajectory in space for simple Earth models was calculated and discussed.

PARAMETRIC INSTABILITY OF INERTIAL WAVES IN A SPHERICAL SHELL

A. Mangeney and **V. Lesueur** (Département de Recherche Spatiale, Observatoire de Meudon, 5 place Jules Janssen, 92195 Meudon Cedex, France)
M. Rieutord (Observatoire Midi-Pyrénées, 14 avenue Edouard Belin, 31400 Toulouse, France)

We study numerically the stability of a finite amplitude inertial wave in a spherical shell of incompressible fluid. The initial condition is made of the superposition of an inertial wave calculated from the linear theory with a finite amplitude plus noise. We discuss the stability of the wave against the decay into other waves and the threshold above which it is necessarily unstable.

Basic mechanisms of the earths rotational geodynamic model

Melnikov O.A., Institute of Marine Geology & Geophysics, Yuzhno-Sakhalinsk, 693002, Russia

The Earth's rotation around its axis as the main and obvious geodynamic factor, operated during the entire time of our planet existence, consists of such 5 basic superimposed mechanisms as rotogenesis, driftogenesis, passive and active riftogenesis and geospherogenesis (separatogenesis), which taken together account for the peculiarities in the Earth's composition and structure in the past and present as well better than any other geodynamic model, including plate tectonics model. Rotogenesis is the more rapid rotation of the Earth's internal shels from west to east relative the external ones, in particular, mantle relative the Earth's crust due to which orogenic belts with mountain roots penetrating into mantle are formed along frintal margins of the displaced continents and then the trench-island arc-marginal sea system along the eastern margins of continents. Driftogenesis is displacement of continental blocks from poles to the equator due to the Earth's rotation. Passive riftogenesis is spreading and formation of the oceanic crust in mid-oceanic risdges due to mantle volume increase as a result of its discompaction by general decrease of the Earth's rotation rate.

Active riftogenesis is spreading of crustal blocks due to rotogenesis and driftogenesis. Separatogenesis (geospherogenesis) is separation of the Earth to geospheres due to its rotation and gravity. Principle schemes of these mechanisms and the main stages of the Earth's development as affected by them.

CONTRIBUTION OF THE SHALLOW SEAS TO THE PRESSURE TERMS OF THE EQUTORIAL COMPONENTS OF THE EAAM FUNCTION

J. Nastula (Space Research Centre, Warsaw 00-716, Poland)
S. Manabe (Earth Rotation Division, National Astronomical Observatory, Mizusawa, 023 Japan)

This paper is to show the contribution of the shallow seas and sea shelves to the pressure term of the Effective Atmospheric Angular Momentum (EAAM) function by computing the residuals of the equatorial components of the EAAM on the basis of two ocean response models. In the first model, the inverted barometric correction (IB) is assumed to be valid on the whole ocean, while in the second model the IB correction is valid only over oceans deeper than 500m. The equatorial components, χ_1 and χ_2, are computed from the Japanese Meteorological Agency's Global Objective Analysis data for the period from 1988 to 1995. The computed residuals exhibit maximum amplitudes in the spectrum range from 10 to 150 days which are of the order of 10^{-7} rad. They show seasonal modulations, especia lly in the spectrum range from 10 to 150 days. The 8, 30,33, 59 and 352-day retrogra de oscillations and about 5,8,72 and 352 prograde oscillations were found in these residuals. The shallow seas areas have no significant influence on coherence and phase spec trum between polar motion and atmospheric excitation functions. The contribution of shallow seas and sea shelves to EAAM function is small but not negligible and can be important for analysis of accuracy of EAAM function.

EARTH ROTATION, SEA LEVEL AND THE ICE-AGE

W.R. Peltier (Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7)

During the most recent 900,000 year period of the Pleistocene epoch, climate system variability has been dominated by a cyclic rhythm of continental ice sheet growth and decay with a characteristic timescale that is almost precisely 100,000 years. A typical glacial phase of the cycle lasts approximately 90,000 years whereas the retreat phase typically lasts of order 10,000 years. The oscillation constitutes a massive perturbation to the hydrological cycle since full glacial conditions are accompanied by a fall of mean global sea level that exceeds 100 metres. This process exerts a profound influence on Earth rotation and in fact has been shown to substantially account for two major anomalies in Earth's current rotational state, namely the non-tidal contribution to the acceleration of axial rotation and the ongoing "true-polar-wander" of the north pole of rotation along the 76° west meridian. I will review and extend the results from a recent series of gravitationally self-consistent analyses of these rotational affects that focus upon the importance of the sea level related component of the forcing. The results of these analyses are expected to play an important role in more fully understanding this signature of ongoing global change in the Earth System.

THE MID-LATITUDAL ATMOSPHERIC CONTRIBUTIONS TO THE POLAR MOTION AND EAAM EXCITATION FUNCTIONS

J. Nastula (Space Research Centre of the Polish Academy of Sciences, Warsaw 00-716, Bartycka 18a, Poland)

In this paper contributions of the equatorial components of the regional Effective Atmospheric Angular Momentum (EAAM) functions both to geodetically determined polar motion excitation and to the global EAAM function variations in the spectral range between 10 and 150 days are investigated. Special attention is given to mid-latitude sectors: in previou s papers they were reported to be important to the excitation of short period polar motion. The regional EAAM functions are computed from the Japanese Meteoro logical Agency's Global Objective Analysis data for the period from 1988 to 1995. We computed the coherence of these functions with the polar motion excitation an d with the global EAAM functions. The results show that, in the case without the inverted barometric (IB) correction to the pressure term, the prograde compo nent of the coherence of regional and atmospheric excitation functions seems to be c onnected with atmospheric variations over both ocean and land, while the retrograde one w ith those over oceans. The IB correction in pressure term results in the shift of coherenc e maxima position over the Eurasia and the North America. The short period oscillations of polar motion excitation functions are mainly co herent with surface pressure variations over northern mid-latitude land areas and this coherence seems to be independent on the inclusion of the IB correction into pressure term of EAAM functions.

INFLUENCE OF ENSO ON CORRELATIONS BETWEEN SEASONAL AND SUBSEASONAL VARIATIONS OF EARTH ROTATION AND ATMOSPHERIC ANGULAR MOMENTUM

M.Nuzhdina (Space Research Centre PAS, Bartycka 18A, Warsaw, Poland. On leave from Kiev Shevchenko Univ. Observatorna 3, Kiev, Ukraine)
B. Kolaczek, W.Kosek (Space Research Centre, PAS, Bartycka 18A, Warsaw, Poland.)

Investigations of subseasonal and semiannual variations of polar motion, length of day, Atmospheric Angular Momentum (AAM) and El Nino, Southern Oscillation Index (SOI) data for a 15- year span (1979-1996) show meaningful influence of El-Nino and SOI (ENSO) on correlations between considered variations of Earth Rotation Paramcters (ERP) and AAM. The above-mentioned correlations and ENSO are correlated with coefficients of the order of 0.5 at the 95of about 0.5- 2 years. Amplitude modulation of the ERP-AAM correlations for the seasonal and subseasonal oscillation ranges is excited by El Nino events. The influence of El Nino on the ERP-AAM correlations is different for different El Nino time series and it is the strongest in the case of Nino 3 and Nino 3-4. Correlations between ENSO and the ERP-AAM correlations are changing periodically with periods of about 2 and 4-5 months. Maxima of coherence for the considered oscillations between polar motion and AAM exitation function are occured during El Nino events.

MODELING SUBSEASONAL POLAR MOTION BY USE OF THE ATMOSPHERIC NORMAL MODES

S. D. Petrov and A. Brzeziński (Space Research Centre, Polish Academy of Sciences, Bartycka 18A, 00-716 Warsaw, Poland)

Recent investigations indicate that the polar motion variability on the subseasonal time scale is governed to a large extent by the atmospheric processes. The linear, or "shallow-water", theory of the atmospheric global circulation provides a decomposition of large scale motion of the atmosphere into individual waves, or normal modes. The most prominent free modes have frequencies in the subseasonal range. The effects of such atmospheric global oscillations have been already observed in the polar motion data. This paper examines their role in the polar motion excitation. At first, we derive a model of the atmospheric angular momentum (AAM) functions based on the "shallow-water" global circulation theory. Then, we estimate the parameters of the effective AAM oscillations related to the atmospheric normal modes from the available polar motion series. The procedure is based on the Kalman filtering technique which permits to account for a realistic continuous power spectrum of the AAM functions. as opposed to the harmonic modeling. The estimated parameters, namely periods and damping factors, may serve for prediction of the polar motion series on the subseasonal time scale, but also as constraints on the atmospheric global circulation models.

ATMOSPHERIC EXCITATION OF ANNUAL TO INTERANNUAL POLAR MOTION

H.-P. Plag and H.-U. Jüttner (Institut für Geophysik, Christian-Albrechts-Universität zu Kiel, Olshausenstr. 40, D-24118 Kiel, Germany)

Based on a modular system model of a rotating Earth, the excitation of polar motion due to atmospheric forcing is investigated. On annual to interannual time scales, the seasonal cycle is the major constituent of atmospheric pressure forcing. On the northern hemisphere, a fourteen to sixteen months oscillation (FSO) constitutes an additional forcing close to the principal rotational free mode of the Earth at approximately 14 months. To study the forced oscillations excited by this atmospheric forcing, long integration times are required to avoid effects of the initial conditions. Therefore, long time series of atmospheric parameters have to be constructed from the relatively sparce climatological observations. Using the available data of the last two hundred years, different atmospheric models are constructed. The sensitivity of the system output to models parameters such as the core-mantle coupling or the ocean's response to air pressure are discussed. It is shown, that for physically reasonable model parameters the FSO is sufficient to excite a model Chandler Wobble. The resulting time-dependence of the model Chandler Wobble is found to agree remarkably with the variations of the observed Chandler Wobble.

DECADAL LENGTH OF THE DAY VARIATIONS EXCITED BY THE ATMOSPHERE.

Abarca del Rio (UMR5566, 14 Av Edouard Belin, 31400 Toulouse, France), D. Gambis (IERS, 61 Av de l'Observatoire, 75014 Paris, France), D.A. Salstein (AER Inc, 840 Memorial Dr, Cambridge, MA 02139, USA)

In this paper we study the atmospheric and oceanic excitation of decadal variation in length of the day over the last thirty years. We will compare these with those arising in a set of atmospheric angular Momentum (AAM) over 1963-1994. Although decadal variation in length of the day are believed to be due to angular Momentum exchanges between the core and the mantle, we show that a decadal period of 10-11 years in LOD (Length of the day) is excited by the atmosphere. Moreover, surface temperature and the tropospheric AAM are in phase with the sunspot numbers : we will then discuss the possibility that both periods (decadal activity on the sun and that of climate) may be related. Although 30 years are not consistent enough to reveal such a period, it appears that LOD and the Southern Oscillation Index series present a peak in power at 14.2 years. And as on interannual periods indications are that there might be a relation between both : the LOD is leading MSOI. This results confirms our prior finding which related an equivalent period in polar motion to SOI, and those by other authors who find this period in global temperature and sea ice fluctuations. This heavily suggest that this period may be real, and though related to the global coupled ocean/atmosphere circuit.

CARDIOID FORM OF ROTATING EARTH AS IT FOLLOWS FROM KOZYREV'S CAUSAL MECHANICS

Rokityansky I.I. (POB-338/7, Kiev-146, Ukraina)

Causal mechanics [Kozyrev N.A. Selected proceedings. Leningrad: LGU, 1991, 445p. In Russian] predicts for rotating bodies an additional "causal" force (CF) directed along the rotation axis. In the parts with greater linear speed of rotation CF is directed to North, in slowly moving (near the axis) parts - to South to ensure the total momentum of CF to be zero. So CF influence the figure of planet imposing cardioid form convex to South that explains North-South asymmetry of gravity field $g_N - g_S \simeq 3 \cdot 10^{-5}\, g > 0$ without forced supposition of more dense matter in Northern hemisphere. On rapidly rotating planets, Jupiter and Saturn, with equatorial speed 10km/s North-South asymmetry reachs $(a_S - a_N)/2\bar{a} \simeq 3 \cdot 10^{-3}$, as Kozyrev measured in 1960-th on the planet's photographs. The presision of the result was on the border of reliability and this measurements should be repeated. Causal mechanics also predicts and explains South deflection of freely falling body.

INTERACTION BETWEEN ATMOSPHERIC ANGULAR MOMENTUM AND EARTH ROTATION VARIATIONS

D.A. Salstein (Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge, MA 02139 USA)

Changes in atmospheric angular momentum (AAM) and in the Earth's rotation are in timately linked because of conservation of angular momentum in the Earth system. AAM variations can be subdivided into those of relative momentum that are due to wind fluctua tions, and planetary momentum due to changes in mass, or pressure, distribution. Meteorological phenomena that are reflected in the Earth rotation signal may be catalogued by time scale. Such signals include interannual fluctuations related to the El Nino/Southern Oscillation over the Pacific Ocean, quasi-biennial oscillations largely from stratospheric wind reversals, solar-forced annual and semiannual variations resulting from the tilt of the Earth's axis, organized behavior on 30-60 day scales, also primarily due to interactions over the Pacific, and synoptic-scale fluctuations of under 10 days, forced by migration of weather systems across mountainous topography. Recently, systems have been developed at meteorological centers to produce multi-decadal analyses by optimally and consistently assimilating past observational data; AAM signals from these reanalyses are more closely related to Earth rotation signals than are those from earlier systems. On century-long time scales, simulations by atmospheric models may now be used to study the low frequency behavior of atmospheric momentum, including trends in its temporal variability, and, by extension, in that of Earth's rotation.

THE EFFECT OF THE POLAR MOTIONS ON ERUPTIONS, EARTHQUAKES, AND L.O.D.

Giancarlo Scalera and Laura Alfonsi (Istituto Nazionale di Geofisica, via di Vigna Murata 605, 00143 Roma, Italy)

The analysis of four databases has been performed searching for periodicity and synchronism in geophysical variables which could be candidates for mutual influence. The analysis have considered the 1900-1995 data of the world wide seismicity, and of the occurrence of volcanic eruptions/year and of the polar motion data. The results, supported by statistical tests, point out an intriguing common periodicity within the four data sets, which suggests the possibility of a still unknown link among these four geophysical processes, link that could be tied to a common triggering cause. The evaluation of the effects of a single strong eruption and a single strong earthquake on the short time scale Earth rotation fluctuations give results which are orders of magnitude smaller than the observed perturbations. The potential effect of major geophysical phenomena on short time-scale Earth rotation variability has been object of much attention in the last decades, in this work we draw the attention toward the possibility that the common periodicity found could be interpreted in the light of an influence of the polar motion on eruptions, earthquakes and L.O.D..
A short review of other already known correlations among different global processes on decade periods is also presented.

WAVELET ANALYSIS OF EARTH ROTATION

M. Schmidt, H. Schmitz-Hübsch and **H. Schuh** (DGFI, Abt. I, Marstallplatz 8, 80538 München, Germany, schuh@dgfi.badw-muenchen.de)

In the wavelet analysis, the harmonic oscillation used in the Fourier analysis is replaced by a wavelet function which is adapted to the signal to be analyzed by shifting and scaling it. Hence, the wavelet transform is an excellent tool for analyzing signals with time-varying amplitudes and/or periods in geodetic and geophysical applications. Series of the Earth rotation parameters published by the IERS and of atmospheric angular momentum data have been analyzed. The energy distribution of the signals is discussed. The analysis of the length of day (lod) yields in the high frequency range the well-known periods of 14 days and of 28 days caused by lunar tides and irregular periodic variations between 40 and 100 days. Very similar irregular variations are visible in zonal wind data. In polar motion, variable periods between 3 and 5 months can be seen in the wavelet spectrum of the short period range which are compared with the equatorial components of atmospheric angular momentum. The differences between the nutation coefficients observed by VLBI and the best-known astronomical nutation model were investigated, too. The wavelet transformation shows an additional nutation component around 430 days which is supposed to be the Free Core Nutation (FCN). The reason for the decrease of its amplitude which is revealed by the wavelet analysis is discussed.

Analysis of GPS-monitored Earth Rotation Variations induced by Ocean Tides and AAM

T.Springer (Astronomisches Institut, Universitöt Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland)
J.Hefty (Department of Theoretical Geodesy, Slovak Technical Univ., Radlinskeho 11, CS-81368 Bratislava, Slovak Republic)
R.Weber (Institut fuer Theoretische Geodaesie und Geophysik, TU-Wien, Gusshausstrasse 27-29, A-1040 Wien, Austria)

At the CODE Analyses Center of the IGS uninterrupted series of subdaily ERPs have been calculated since May 1995. In addition, as recommended by the IGS and according to the IERs conventions, all global IGS Analyses Centers have implemented the apriori tide model by Ray (1995) since July 1996, which describes subdaily ERP variations. In 1996 the accuracy of ERP- estimates based on GPS observations has reached a level of 0.1 - 0.2 mas. This allows for detailed investigations concerning the influence of ocean tides on polar motion and a continous improvement of the CODE ocean-tide model. Furthermore, the authors intend to present first results concerning correlations of AAM-induced polar motion and GPS-observed values after removal of the tidal terms.

ESTIMATION OF THE EOP FROM VLBI DATA USING LEAST-SQUARES COLLOCATION METHOD

O.A. Titov (Institute of Applied Astronomy, Zhdanovskaya str., 8, 197110, Sanct-Petersburg, Russia)

Subdiurnal EOP variations are subject of special interest because they are affected by different natural phenomena (ocean tidal, near diurnal nutation, etc.). Conventional approach for VLBI data analysis allows to receive one estimate from 24-hours experiment only. Least-squares collocation method (LSCM) is suggested as an alternative one to estimate variations of EOP with high temporal resolution. The approach has been applied for CONT'94 experiment processing. All reductional calculations have been made using OCCAM (V3.3) package. Estimates of four main ocean tidal amplitudes are in a good agreement with other authors ones. After that the power spectrum density of post-fit residuals the at the range from a few minutes to three days has been calculated as well.

ESTIMATION OF THE MODEL PARAMETERS FOR PREDICTION OF EARTH ROTATION PARAMETERS

I.M. Tsyupak (State University "Lviv Polytechnic", S.Bandera St. 12, 290646 Lviv-13, Ukraine)

The adopted models for prediction of pole coordinates and Universal Time consist of two parts: the mathematical and the stochastic models. The mathematical model is based on sum of Fourier series with different periods. The mathematical model for prediction of pole coordinates has three basic periods: 6-year, Chandler and annual ones. Besides, these amplitudes wobble have represented function of time and at the same time these basic periods depended functional from amplitude of variations. Estimation of the model parameters implemented by Least-Squares method.

ON THE JOINT USE OF THE ASTRONOMICAL, GEODETIC AND GEOPHYSICAL OBSERVATION DATA FOR TESTING THE GEOPHYSICAL HYPOTHESES

A.Gozhy, **M.Tyshchuk** (Poltava Gravimetrical Observatory, Myasoyedova Str. 27/29, 314029 Poltava, Ukraine)

Nowadays the verifications of the geophysical hypotheses on the evolution of the Earth's figure is of both great scientific impotance and practical significance. In particular, the objective information on the changes of the Earth's shape, dimensions and topography form the basis for studying the mechanics of the earthquake occurrence. However, the lack of any significant advance in the earthquake forecasting testifies to the fact that the plate tectonics hypothesis hardly reflects the reality. Under these circumstances it is necessary to use other hypotheses, such as that of the Earth's expansion, Earth's pulsation, Earth's contraction. The principal difficulty to check the geophysical hypotheses lies in the fact that the contemporary precision of the astronomical, geodetic, geophysical observations is insufficient under the short time intervals. In such a situation it is the data of the long-term combined observations at the same stations that can be used for verification. All-round analysis with the case of checking the non-rotating spherical Earth model has shown the essential differences in the character of arcs changing between the zeniths of the supporting points and of the chords between them depending on the relevant hypothesis.

PECULIARITIES OF 27-DAY VARIATIONS OF A LENGTH OF DAY DUE TO SOLAR ACTIVITY

Zakharov I.G., Tyrnov O.F. Kharkiv State University, Kharkiv, Ukraine

Using data over 1973-1976, it is shown that amplitudes of variations of the length of day, dP, due to solar activity, are closely related to changes of a full energy of solar wind flow. The dP-variaions may be approximately estimated using an amplitude of 27-day variations of solar radio frequency flux F10.7 and a number of days having a negative polarity of the interplanetary magnetic field (IMF). There have been considered peculiarities of this relationship over two last solar activity cycles. There have been investigated time delay of dP-changes with respect to variations of the solar activity parameters, and peculiarities of 27 - day variations of dP for 2- and 4-sector structures of the IMF.

Effect of the atmosphere on the Earth rotation by the torque ap proach with application to the Earth's nutations

O. de Viron, Ch. Bizouard, V. Dehant (Royal Observatory of Belgium, Av. Circulaire, 1180 Bruxelles, Beligum)

The purpose of this presentation is the evaluation of the effects of the a mosphere on the Earth's rotation. The expressions of the torques acting o the Earth are derived from the angular momentum conservation equatio These torques are evaluated numerically by using a spherical harmonics a proach and their orders of magnitude are intercompared.

The analytical expression of the torque deduced from the angular m mentum conservation is used to compute atmospheric effect on the nutatio of the Earth

Impact of Sea Level Variations on Geodetic Observables

Jianli Chen[1,3], Clark R. Wilson[1,2,3] and C.K. Shum[1]
[1]Center for Space Research,[2]Institute for Geophysics,
[3]Department of Geological Sciences, University of Texas at Austin

A number of geodetic variations, such as polar motion and geocenter variations, are the physical consequences of mass movement within the Earth system. Atmospheric mass redistribution at the several-millibar level is known to be an important contributor, and atmospheric variations are relatively easy to monitor using global general circulation models. The oceans are generally believed to be responsible for some of the observed variations, because load variations of several centimeters of water, equivalent to several millibars of atmospheric mass, are likely, although more difficult to observe. TOPEX/Poseidon altimeter observation provide one method to monitor mass redistribution within the oceans on a global basis. Using more than four years of TOPEX/Poseidon data, we investigate global sea level anomalies, and estimate the corresponding mass load variations over the oceans and their contributions to seven available space geodetic time series, including two components of polar motion, length-of-day (LOD), three components of geocenter positions, and the nodal precession rate of Lageos-1. Steric thermal expansion in sea level variations is estimated using the objectively analyzed temperature fields in the 94 World Ocean Atlas. Comparison between observed geodetic variations(with atmospheric contributions removed) and inferred contributions from the oceans shows that mass load variations associated with sea level variations play an important role in most of the geodetic time series.

NUTATION OF THE NONHYDROSTATIC MODEL OF THE EARTH

N.A.Tchouikova, S.A.Kazarjan, V.E.Zharov
(Sternberg State Astronomi cal Institute, Universitetskij pr-t,13, 119899, Moscow,Russia)

Using the seismological and gravitational data the nonhydrostatic model of the Earth was derived. The momens of inertia and displacements of the mass centers of the different envelops of the Earth (crust, mantle and core) were calculated. The additional ellipticity of the core ($\Delta e = 0.00032 \pm 0.00024$) and the off-diagonal moments of inertia tensor of the envelops were calculated. On base of these data the corrections of the second order to the Sasao - Ocubo - Saito equations of the Earth rotation were determined using the simple two-envelops model. The amplitudes of the major nutation terms were found. The additional consideration of the effects of atmospheric and ocean tides, mantle anelasticity lead to value of the free core nutation (FCN) frequence is equal to -1.002334Ω, that close to the observed value (-1.002320Ω).

ON THE EXCITATION OF THE CHANDLER WOBBLE

Ya.S. Yatskiv (Main Astronomical Observatory, National Academy of Sciences, 252650 Kyiv-22, Ukraine)

Different models for describing the Chandler wobble and the excitation sources of this wobble are reviewed. The possibility of the quasi-periodic excitation is discussed.

SE13/G9 Modelling of global change phenomena with observational geodetic and geophysical constraints

Convener: Plag, H.-P.
Co-Convener: Chao, B.F.

Secular Variations of the Zonal Gravity Field and Polar Motion as Geophysical Constraints

B.Chao, F. Lemoine (Laboratory for Terrestrial Physics, NASA/GSFC, Greenbelt, MD 20771)
S.Klosko, N. Pavlis (Hughes STX, 7701 Greenbelt Rd, Greenbelt, MD 20770)

Satellite Laser Ranging (SLR) data have been analyzed by ourselves and several groups to provide estimates of the secular variations in the zonal harmonics of the geopotential field. While the SLR data available from late-1992 onward are superior in satellite and temporal coverage (two station shifts in operation by the NASA Network), SLR data extending back to the mid-1970s have been utilized by some of the analysis centers. Three solutions for secular zonals and the SPACE'93 secular polar motion rates are evaluated to provide constraints on geophysical models describing post-glacial rebound (PGR) and ice sheet mass balance/sea level rise using an inverse method. The benefits of forward modeling the water impoundment in reservoirs and the contributions of the mountain glaciers to the observed secular terms are discussed. Although the number of well resolved time dependent geopotential terms is limited, the inverse solutions are promising and provide results consistent with IPCC estimates of ice sheet mass balance. New approaches for improving the resolution of the time varying gravity model by extending the observations to the behavior of the low degree tesseral terms will also be discussed.

MODELING ENVIRONMENTAL LOADING EFFECTS

T van Dam (NOAA/CIRES, Campus Box 216, University of Colorado, Boulder, CO 80309; ph. 303-492-5670; fax 303-492-1149; Internet: tonie@robeson.colorado.edu);
J Wahr (Dept. of Physics/CIRES, Campus Box 390, Universtiy of Colorado, Boulder, CO 80309; ph. 303-492-8349; Internet: wahr@longo.colorado.edu);
G Sasagawa, NOAA-N/OES12 8600 North 39th Street, Longmont, CO 80503; ph. 303-497-7405; Internet: glenn@robeson.colorado.edu)

Temporal variations in the geographic distribution of atmospheric and oceanic mass, load and deform the surface of the earth. Atmospheric pressure changes associated with the passage of high and low pressure systems can cause the surface of the earth to move vertically by up to 2 cm. These surface displacements account for up to 24% of the total variance in GPS height estimates. Gravity observations, while sensitive to the crustal motions associated with atmospheric loading, are also sensitive to the load itself. Pressure loading effects are routinely removed from gravity time series by fitting local pressure values to the observed gravity changes. We will present results which demonstrate that removing the effects of the deformation from the gravity data before performing the regression with pressure, reduces the RMS of the gravity data even further.

Non-tidal variability in the distribution of oceanic mass can cause deformations at coastal stations of up to 1 cm over a few day period. We estimate non-tidal ocean loading effects by convolving ocean bottom pressure changes predicted by an ocean general circulation model with Farrell's Greens functions. We will compare these loading estimates with geodetic data from coastal stations.

Finally, changes in water storage can also induce loading effects that are detectable with geodetic techniques. Using a global data set for soil moisture and snow mass, we estimate the spatial and temporal characteristics of the loading effects.

ATMOSPHERIC ANGULAR MOMENTUM FLUCTUATIONS DURING THE PERIOD 1979-1988 SIMULATED IN NUMERICAL GLOBAL CIRCULATION MODELS

R.Hide (Dept. of Physics, University, Oxford OX1 3PU, England, U.K.)
J.O.Dickey & S.L.Marcus (J.P.L., Pasadena, California 91109, U.S.A.)
R.D.Rosen & D.A.Salstein (A.E R., Cambridge, Mass. 02139, U.S.A.)

Major global dynamical phenomena in the Earth's atmosphere are manifested in time series of atmospheric angular momentum (AAM) fluctuations, as determined directly from meteorological observations and indirectly from geodetic observations of fluctuations in the rotation of the solid Earth. AAM fluctuations are intimately linked (a) with energetic processes throughout the whole atmosphere, and (b) with the action of tangential surface stresses.in turbulent boundary layers and of normal stresses over orography. One stringent test of any numerical global circulation model (GCM) is provided by an assessment of its ability to represent AAM fluctuations on timescales ranging from days to years. From monthly data made available through the Atmospheric Model Intercomparison Project (AMIP) of the World Climate Research Programme, we investigated in the first instance the seasonal and interannual fluctuations in the axial component of AAM as simulated by 23 of the AMIP GCM's for the period 1979-1988, during which two major "El Nino" events occurred. The detailed findings of these intercomparisons are given in a paper to be published in the Journal of Geophysical Research.

THE IRREGULAR SYNCHRONOUS VARIATIONS OF GEOPARAMETERS AT EL NINO PERIODS

S. Yu. Khomutov, V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3. Novosibirsk 630090, Russia)

The occurence of the abrupt sporadic temporary variations of the condition in the external and internal geoshells and in the near-Earth space environment which are synchronous with the EN-epochs is considered. In particular, the sudden change of the global characteristics such as the speed and density of the solar wind, the intensity of the cosmic rays, aa- and Dst- indices, the vertical and horizontal components of the geomagnetic field, the rotation and seismicity of the Earth at the period 1982-1983, which is known as the most significant EN-event at our century, is observed. Such anomalies have occured partly at 1972-1973 and 1991-1994 El Nino. The possible cause of the most geoeffective El Nino is the influx of the solar energy at the ionosphere and magnetosphere and the further its transfer to "atmosphere-ocean" system and to the Earth's inner shells.

DETERMINING OCEAN CIRCULATION FROM ALTIMETRIC SEA LEVEL MEASUREMENTS

L.-L. Fu (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA)

The sea-surface elevation relative to the geoid is a dynamic boundary condition for the three-dimensional oceanic pressure field. This boundary condition has been determined over the global ocean every 10 days by a precision radar altimeter aboard the TOPEX/POSEIDON satellite since October, 1992. This is the most accurate altimeter data stream to date for the study of the ocean general circulation and its variability. The determination of the absolute surface geostrophic currents is limited to scales larger than spherical harmonics of degree and order 14 due to the uncertainty in the current geoid models at smaller scales. However, the precise sea level measured along repeat satellite ground tracks allows accurate determination of the temporal variabilities of the ocean from basin scales to mesoscales (10-10,000 km). Scientific highlights of this longest-running altimetric satellite mission include improvements in our understanding of the dynamics and thermodynamics of large-scale ocean variability, such as, the properties of planetary waves; the energetics of basin-wide gyres; the heat budget of the ocean; and the ocean's response to wind forcing. These data provide a unique test-bed for global ocean models and have set the stage for operational ocean applications. Looking to the future, all spacecraft systems remain healthy and we are optimistic TOPEX/POSEIDON will produce many more years of global sea level data. Moreover, a series of future altimetric satellites will ensure the continuation of the data stream into the next century for providing a key measurement to understand and monitor global change.

INFLUENCE OF THE EARTH'S CORE ON CHANGES IN EARTH ROTATION

A. Jackson (Dept. of Earth Sciences, Leeds University, Leeds, UK.)

Variations in the Earth's rotation rate on the timescale of decades have traditionally been attributed to exchange of angular momentum between core and mantle. It is only recently that quantitative evidence for such an exchange has been forthcoming. We report on calculations to determine the time variations in the flow at the top of the core from magnetic data. Such calculations can say nothing concrete about the flow within the core. However, a theory for the response of the core to topographic torques acting at the core-mantle interface predicts that the response should be independent of the coordinate parallel to the rotation axis. We observe that flow solutions have significantly different temporal variations in the zonal toroidal modes which are symmetric about the equator, compared to the anti-symmetric modes. We suggest this indicates that we are observing relatively rapid changes responsible for altering the core's, and therefore the mantle's, angular momentum. A quantitative evaluation of the predicted changes in the Earth's rotation rate is very encouraging. The most recent changes in the rotation rate will be discussed in this context.

SEISMICITY OF THE SOUTH-WEST PACIFIC AND EL NINO EVENTS

S. Yu. Khomutov, V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3. Novosibirsk 630090, Russia)

Seismicity of the south-west part of Pacific for 1975-1994 is analyzed using the data of NEIC catalogue. It is shown by us that seismic activity at the Tonga and Kermadek trenches is appreciably increased at the January 1976, December 1982 and October 1986. The allocated events represent compact groups of shallow earthquakes with spatial-temporal extent about 100 km and 5-10 days and with the similar source mechanisms. The temporary position of these clusters is closed to El Nino epoches with probability of random coincidence not more than 0.02some increase of seismic activity at examined region. The trigger-effect of dynamic loads on the lithosphere when the normal atmosphere-ocean circulation is disturbed is considered.

SEA LEVEL VARIATIONS AND SEA SURFAE TEMPERATURE CHANGES FROM SATELLITES.

Per Knudsen and Ole Baltazar Andersen (Kort & Matrikelstyrelsen, Rentemestervej 8, 2400 Copenhagen NV. Denmark, E-mail: pk@kms.min.dk, oa@kms.min.dk)

The sea level is monitored globally from satellites. Hence, the spatial scales of the sea level variations observed locally at tide gauges can be analysed. In studies of Global Change sea surface temperature (SST) data may give valuable information. Global SST data may indicate changes in the heat budget of the oceans. Four years of sea surface temperature (SST) data and sea level anomalies (SLA) for the same period is analysed. Data are the low resolution 0.5° by 0.5° averaged temperature data from the Along Track Scanning Radiometer (ATSR) data onboard the ERS 1 satellite mission, and TOPEX altimetry from the TOPEX/POSEIDON satellite. Annual signals and changes in the annual signal in SST and SLA for the years 1993 and 1994 are investigated. The rate of global mean sea level change during 1993-1996 is investigated and compared to tide gauge observations. The changes in mean sea level are compared with changes in SST to decide whether the change in sea level is related to changes in the heat content of the mixed layer. Initial results show that this is only true for some regions, whereas no correlations between changes in SST and SLA are found in other regions.

BIFROST PROJECT: GPS MEASUREMENTS TO CONSTRAIN GEODYNAMIC PROCESSES IN FENNOSCANDIA

J X Mitrovica[1], James L Davis[2], H-G Scherneck[3] and J M Johansson[3] (1. Department of Physics, University of Toronto, Toronto, Canada, M5S 1A7, jxm@physics.utoronto.ca; 2. Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; 3. Chalmers University of Technology, Onsala Space Observatory, S-439 92 Onsala, Sweden)

The response of the Earth to the final glacial cycle of the current ice age is manifest in a wide range of geophysical observables, including a globally distributed set of sea level variations and anomalies in both the gravitational field and rotational dynamics of the planet. With the advent and improvement of remarkably precise space geodetic techniques this list has grown to include present-day 3-D crustal deformation rates. The BIFROST Project (see *EOS*, 77, No. 35, p. 337) is a multi-national effort to acquire and interpret data from continuous Global Positioning System (GPS) surveying in Fennoscandia. The BIFROST GPS network, which has been operational since August 1993, is comprised of 21 Swedish sites which form the SWEPOS sub-network and a further 10 European sites operating for the IGS. The geophysical goals of the project are to use the estimated 3-D site velocity vectors to (1) correct the extensive Fennoscandian tide gauge record of sea level change for the influence of vertical motions; (2) infer the rheology of the mantle below Fennoscandia; and (3) constrain the space-time history of the Late Pleistocene ice load in the region. In this talk I describe the progress of the project from our early detection of a GIA signal to our present efforts to address long-term goals.

CLIMATE CHANGE IN THE URALS, RUSSIA, RECORDED IN BOREHOLE TEMPERATURES AND METEOROLOGICAL DATA

P. Stulc (Geophysical Institute, Czech Academy of Science, Bocni II/ 1403, Prague, 141 31, Czech Republic)
I.V. Golovanova, G.V. Selezniova (Institute of Geology, Russian Academy of Science, K.Marx St. 16/2, Ufa, 450 000, Russia)

Primary evidence of global warming, which comes from surface air temperature (SAT) data, is generally constrained to the last century. However, since the earth continuously records ground surface temperature (GST) variations, information on earlier climate change is potentially contained in borehole temperatures. We analysed temperatures measured in 31 boreholes in the south Urals, situated in a N-S oriented band 1000 km long. Different inversion strategies were evaluated as the appropriate way of recovery of the climate signal from borehole data has not been settled yet. The results (consistent throughout the studied region) represent a robust estimate of regional GST history: a cold period of 0.5-1.0 K bellow the long term mean (LTM) culminated in 1700-1750. GSTs then warmed to about 1 K above LTM by 1980, consistent with warming indicated by 160 year long SAT records.

MODEL OF THE EARTH'S MAGNETIC POLE MOTION NOWADAYS IN THE GEOLOGIC PAST

V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3, Novosibirsk 630090, Russia)

The idea of this model is that the magnetic pole drift is caused by the change of the intensity of the main (dipile) field and the field of the global magnetic anomalies which intensities change regardless of the main field. We have verified this hypothesis using the data of studying the modern drift of the North magnetic pole (NMP) and the South magnetic pole (SMP). In particular, the NMP-location in 1994 was predicted by us. The observations of this location have confirmed our prediction with high accuracy. Based on the analysis of the observations by the magnetic observatories, we have introduced a correction into the location of the NMP measured in 1831 and the location of the SMP measured in 1909. The application of our hypothesis has permited us to explain the character of the magnetic pole motion during the reversal. The comparison the modern velocity of the NMP- and SMP-motion with the TPW five orders of magnitude less than velocity, which is shows that the reversal of the Earth's magnetic field takes place nowadays. The observations of the magnetic observatories and the hypothesis elaborated by us permit to interpret in a new way the palaeomagnetic data on the palaeopoles motion.

Space Geodetic Measurements of Plate Motion

D. E. Smith and R. Kolenkiewicz (Laboratory for Terrestrial Physics, NASA/GSFC Code 920, Greenbelt, MD 20771, USA)
P. J. Dunn and M. H. Torrence (Hughes STX Corp., 7701 Greenbelt Rd., Greenbelt, MD 20770, USA)

The refinement of tectonic plate motion models has important implications for geodetic and geophysical constraints on models of global change. We describe an analysis in which a combined network of space geodetic instruments has been used to produce a velocity solution for seven major tectonic plates. Satellite Laser Ranging, Very Long Baseline Interferometry, the Global Positioning System and DORIS technologies provide a continuous sequence of measurements long enough to define a plate motion model. Collocated stations can more accurately define the station's horizontal and vertical position, as each technique is sensitive to different error sources. Data from instruments at separate locations can then be effectively combined to significantly extend the total network as instrument and local geodetic error models improve. A least squares approximation algorithm is used to compute relative spherical rates from the solutions derived from SLR (GSFC), VLBI (GSFC), GPS (JPL), and DORIS (GRGS/CNES). This information is utilized to place the estimated horizontal components of site motions in a single kinematic frame. Relative rotation poles, computed from the estimated site velocities, show some differences from the plate rotation poles given by the NUVEL-1A geophysical model. When the broad scale plate motions are removed from site velocities located in boundary zones, regional patterns of strain are seen in North and South America, Japan and the Mediterranean region.

MODELLING OF GLOBAL CLIMATE CHANGE WITH OBSERVATIONAL GEOTHERMAL CONSTRAINTS.

V.B.Svalova (VNIIGeosystem, Russian Ac. of Sci, Varshavskoje shosse 8, 113105 Moscow, Russia).

For correct climate reconstruction of the last two centuries by geothermal data it is necessary to combine and analyse the temperature logs for stable boreholes of 200-300 meters depth, heat conductivity data for sedimentary cover layers, relationships between air and ground temperatures, to evaluate the effects of hydrogeological factors. More than 80 geothermal borehole data for Russian Platform were collected. 11 temperature logs of Belgorod region were investigated. The inversion showed ground surface temperature minimum between 1500-1750 with pronounced warming thereafter reaching maximum at about 1900. The 20th century is characterized by some cooling and later on by recent warming. Air temperature analysis from 1821 to 1965 for Moscow region shows increasing of middle year temperature every ten years of 0.1 oC, but there was minimum around 1860 and maximum near 1930. The comparison of temperature trends for Moscow and adjacent regions of Russian Platform gives possibility to evaluate the warming industrial effect, that is very important for ecological problems decision. The geothermal method of past climate assessment yields temperature of the Earth's surface, which may be different from local air temperature which is subjected to hydrogeologic and ecological conditions and reflects also man-made interferences. The pure climatic effect is thus not always evident. More than 200 data on air-ground temperature relationships were analysed. The analysis of modelling for different regions shows similar results for Russian Platform, South Ural and Kirgistan (Issik-Kul area). The results of paleoclimate reconstructions for West Siberia differ from them due to permafrost zone effect.

The Earth's orbital cycles and variations in the geomagnetic field

D. H. Tarling (Dept. Geological Sciences, University of Plymouth, PL4 8AA, England), M. Iorio (Geomare sud, Research Institute, C.N.R., Via Vespucci 10, Napoli, Italy) and B. D'Argenio (Dip. Scienze della Terra, Univ. di Napoli, Largo San Marcellino 10, Napoli, Italy)

The sedimentological, lithological and magnetic (scalar and vector) properties of Early Cretaceous carbonate sequences in the Southern Apennines, Italy, all show identical spectral signatures that correlate with periodicities expected from changes in all of the Earth's orbital parameters. The intensity of oceanic magnetic anomaly profiles in the South Atlantic and Pacific Oceans (Cenozoic and Cretaceous, respectively) also show correlations with long term periodicities in the Earth's orbital parameters. These correlations, in radically different environments, indicate that changes in the Earth's orbit has major effects on the scalar and vector properties of the geomagnetic field. They also enable astronomical regularities to be used as a dating technique for geophysical and geological purposes that, in specific environments, enable correlations at a 1 cm level, corresponding to a time equivalent of some 360±20 years some 120 Ma ago.

SE14 Near-surface geophysics: archaeological prospection and archaeomagnetic dating

Conveners: Faßbinder, J.; Hoffmann, V.

01 Archaeological prospection

Convener: Schmidt, A.
Co-Convener: Faßbinder, J.

ARCHAEOLOGICAL PROSPECTION OF WALL RELICTS USING DC-GEOELECTRICITY AND GPR

J. WILHELM and E. APPEL (Institut für Geologie und Paläontologie, Universität Tübingen, Sigwartstr. 10, 72076 Tübingen, Germany)

DC-geoelectrical mapping was carried out on a 100mx100m area with buried wall relicts of ancient roman farm-houses. A twinpole configuration was used with spacing of 0.5m and grid width of 0.5m. Apparent resistivities vary between 8-12 Ohm*m for the background and 15-25 Ohm*m over wall structures consisting of calcareous material. Results show detailed contours of three buildings and of a possible drainage system. Different arrays and electrode spacings were tested on selected sections across known walls. Tripole measurements provide a good first survey concerning the strike direction of structures. Two-dimensional geolectrical modelling yield wall depths of 0.5-1m and are in agreement with ground-penetrating radar measurements using bistatic 500MHz antenna.

THE APPLICATION OF GPR IN THE INVESTIGATION OF THE MAGDALENIEN-SITE AT BURGÄSCHISEE (BE), SWITZERLAND

M. A. ATYA (National Research Institute of Astronomy and Geophysics, 11421 Helwan, Cairo, Egypt)
C. Schlüchter (Institute of Geology, University of Berne, Baltzerstrasse 1, CH-3012 Berne)

GPR measurements were carried out on the SW and S stations at Burgäschisee (BE), Switzerland. At the SW station measurements were done to investigate the ancient shoreline of the lake, at the S station the actual shoreline was analysed. With a 4m depth penetration at the SW station and about 1.8m at the S station, both the ancient and the present lake shore were mapped with their GPR facies. Our investigations are used as the background information to plan detailed excavation at this important Magdalenien-site.

Comparison of Geophysical Prospecting Methods at Qantir-Piramesse (Egypt)

Helmut Becker and Jörg Faßbinder (Bayer. Landesamt für Denkmalpflege, Dept. Archaeological Prospection & Aerial Archaeology, Hofgraben 4, D-80076 München, Germany)
Hatem Oda, Tareq Fahmy, Ahmed El Said Syed and Gad El Qadi (National Research Institute of Astronomy and Geophysics, Helwan, Cairo, Egypt)

Sponsored by the Volkswagen-Stiftung, a combined prospection with Caesium Magnetometer Scintrex SM4G-Special with Duo-Sensors (Munich), Fluxgate Gradiometer Geoscan FM36 and resistivity meter Geoscan RM15 (both from Helwan) was undertaken at Qantir-Piramesse. This site in the Nile delta, beeing excavated by the Pelizäus-Museum (Hildesheim, Germany) and covering about 30 km2 was identified as the ancient capital of Ramsses II. The aim of the project was testing geophysical methods for prospecting mudbrick architecture. Mudbrick walls and sand-foundations showed up in magnetics as negative alignements. Resistivity gave the difference between sand- and stone-foundations, but no mudbricks. Archaeological structures at deeper depths were only detected by caesium magnetometer, which is four times faster than the fluxgate. Therefore caesium magnetometry with multi-sensor technique may be the most suitable method for the evaluation of "city maps" in the Nile delta and elsewhere.

Multi-Sensor Configurations for High-speed / High-resolution Archaeological Prospection with Caesium Magnetometry

Helmut Becker (Bayer. Landesamt für Denkmalpflege, Dept. for Archaeological Prospection & Aerial Archaeology, Hofgraben 4, D-80076 München, Germany)

Caesium magnetometry offers high sensitivity (10 to 1 Picotesla) and high speeds (0.1 sec per sample) for magnetic prospecting. Modern instruments have electronic bandpass filters selectable for 0.7 to 8 Hz, which cancel most technical (power lines, electric railways etc.) and natural (micropulsations) high frequency geomagnetic disturbances. The two sensors of gradiometer systems may be moved in the field parallel for two total field measurements at the same hight above ground as a **duo-sensor** configuration. The geomagnetic diurnal variation can be reduced by the calculation of the line- or square-mean in a 20(40)m-grid. A **quadro-sensor** system, which may be controlled by a single operator too, allows about 500.000 measurements per day (2.5 hectar with 0.5/0.1 m sample raster). Strong geomagnetic temporal variations (magnetic storms) may be compensated by a fifth sensor in variometer mode. The prospection of different archaeological sites like Monte da Ponte (Chalkolithic fortification, Portugal), Ostia Antiqua (ancient harbour-city of Rome, Italy) or Qantir-Piramesse (capital of Ramsses II, Egypt) demonstrate the power of this new technique for archaeology.

HUNTING THE EVIDENCE - AIRBORNE PROSPECTION OF SNOW AND DAMP MARKS

Otto Braasch (Matthias-Hoesl-Str. 6, D-84034 Landshut, Germany)

During all seasons in Central Europe archaeological air survey is performed employing light planes with "organic" sensors (human eyes) on board. In contrary to any "remote sensing", this type of prospection requires on spot identification and interpretation of archaeological traces, which mostly are observed in vegetation and ploughed soil, by the crew. Through colour slides the audience is taken up for a flight over agricultural landscapes covered by a thin snow layer and over damp loess fields, which are drying up in sunshine. Detected features, having been documented on conventional chemical films are discussed and interpreted as prehistoric relicts. Since the exotic phenomena shown in snow and on damp fields origin in temperature differentials, this rather rare facet of the visual survey method might be considered as "Using the poor man's thermoscanner". Following the display, the increased application of modern thermo detecting and recording systems in archaeological prospection might be considered - once the "cheap" media of snow and moisture are absent.

INTEGRATED ARCHAEOLOGICAL PROSPECTION IN RUGGED ALPINE TOPOGRAPHY: THE BOCKHART PROJECT (VALLEY OF GASTEIN) ON THE HISTORICAL "TAUERNGOLD"

Brigitte Cech (Institut für Ur-und Frühgeschichte, Univ.Wien, Franz-Kleingasse 1, A-1190 Wien)
Georg Walach (Institut für Geophysik, Montanuniversität, Franz-Josef-Straße 18, A-8700 Leoben)

This interdisciplinary project is an examplatory work on gold production in the 16th century following the course of the ore from the mines to the dressing plants and the smelting sites. In addition to these technical aspects the project also deals with the living and working conditions of the miners. General methods of prospection were aerial photography, systematical survey and geophysics. The specific methods employed in geophysical prospection were geomagnetics, electromagnetics (EMI) and self potential measurements. The results of the above mentioned methods defined the sites of the actual dig and gave the archeaologist detailed information valuable for the excavation and the general interpretation of the sites.

ANALYTICAL CALCULATION FOR DIFFERENT TYPES OF SETTLEMENT STRUCTURES

G.Dittrich (Universität Leipzig, Institut für Geophysik und Geologie, Talstraße 35, 04103 Leipzig, Germany)

Archaeometrical investigations are often involved with the exploration and the following interpretation of settlement structures using geomagnetics. On this occasion the problem frequently exists to interprete geomagnetic anomalies of inner structures like remainings of houses, streets or cemetries. On the one hand these problems arise from a deviation of the anomalie structure with regard to the expected geometrical shape and on the other hand in a particular failing detection of structures due to false probe-configurations and measurement grids. A further problem is to differenciate between archaeological and geological components.

The different building materials and constructions used are leading to different types and dynamics of anomalies. The analytical modelling of these various types of structures yields relevant information about the shape and dynamic to be expected. In this case additional factors have to be taken into consideration: for instance the inhomogeneous distribution of the susceptibility parameter in amount and orientation, the incomplete maintenance of the objects and the geological situation. This knowledge is also helpful for the elaboration of models for numerical inversion calculations of their parameters.

If primary information exists about the age of the settlement and the geology, it is easier to prepare and to carry out the measurements and to compare the detected structures with a catalogue of typical anomalies. This improves the content of information and the certainty of the interpretation.

3D-COMBINATION OF GROUND MAGNETICS AND AERIAL PHOTOGRAPHS IN ARCHAEOLOGICAL PROSPECTION

M. Doneus (University of Vienna, Institute for Prehistory, Aerial Archive, Franz Kleingasse 1, A- 1190 Wien, Michael.Doneus@univie.ac.at)
W. Neubauer (University of Vienna, IDEA, Dept. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Wien, Wolfgang.Neubauer@univie.ac.at)
A. Eder-Hinterleitner (Vienna University of Technology, Institute for Automation, Pattern Recognition and Image Processing Group, Treitlstrasse 3, A-1040 Wien, ahi@prip.tuwien.ac.at)

High resolution magnetic surveys with optically pumped Caesiumgradiometers are visualized as digital images and interpreted on vectorized graphic layers. 3D-modelling of the processed magnetic data allows to derive 3D reconstructions of the archaeological features.
Interpretation of aerial photographs is done by introducing analytical photogrammetry. Products are vectorized interpretation maps, digital terrain models, vectorized isolines and digitally rectified photographs with an accuracy of down to 10 cm.
All this kind of different output is digitally combined to create additional images for consecutive archaeological interpretation. The 3D-data sets of the various combinations are explored using the scientific visualization system AVS and the geographic information system ArcInfo.

CREATING 3D-VIEWS OF PREHISTORIC MONUMENTS USING PROSPECTION DATA

M. Doneus (University of Vienna, Institute for Prehistory, Aerial Archive, Franz Kleingasse 1, A- 1190 Wien, Michael.Doneus@univie.ac.at)
W. Neubauer (University of Vienna, IDEA, Dept. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Wien, Wolfgang.Neubauer@univie.ac.at)
A. Eder-Hinterleitner (Vienna University of Technology, Institute for Automation, Pattern Recognition and Image Processing Group, Treitlstrasse 3, A-1040 Wien, ahi@prip.tuwien.ac.at)

By combinig digital terrain models (DTM) derived from aerial photographs with high resolution magnetic prospection, impressive views of ancient monuments are created.
The results of the 3D-modelling of the magnetic data are inserted in the DTM. Images as magnetograms, digital aerial photographs, reconstructions of the ancient environments or photographs from excavated parts of the monuments can hierarchically be mapped on the terrain model. Additional integration of reconstructed archaeological features based on additional excavation data produces a virtual model of monuments that had been covered by soil over thousands of years, bringing them back to (virtual) life.

IMPROVEMENTS OF 3D MAGNETIC MODELLING AND RECONSTRUCTION THROUGH AN ARCHAEOLOGICAL-GEOPHYSICAL EXPERIMENT

A. EDER-HINTERLEITNER (Vienna University of Technology, Institute for Automation, Pattern Recognition and Image Processing Group, Treitlstrasse 3, A-1040 Vienna, ahi@prip.tuwien.ac.at)
W. NEUBAUER (University of Vienna, IDEA, Dept. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Vienna, Wolfgang.Neubauer@univie.ac.at)

The archaeological-geophysical experiment at the neolithic circular ditch Schletz, where layers of different sediments of the ditch-filling were excavated, registered by a tachymeter and magnetically analysed lead to a precise understanding of their size and magnetic influence. The consequence of these results for the 3D modelling are an improvement of the magnetic model of the filled ditch and a reversal of the ditch modelling within reconstruction algorithm.
The model of the ditch is changed from a magnetically homogeneous body to a body with layers of different magnetic properties. Within the iterative reconstruction algorithm the ditch is now modelled from its bottom to the earth's surface. These improvements lead to more accurate reconstruction results.

LES AVANTAGES DU CHAMP TOURNANT ELECTRIQUE DANS LA RESOLUTION DES PROBLEMES ARCHEOLOGIQUES D'APRES LES DONNEES DE LA MODELISATION MATHEMATIQUE

Dr. Ermokhine K.M. /Mining Institut of S-t Petersburg , 21- lin. V.O. N 2, RUSSIE / Dr. Sapojnikov B.G./ NPO RUDGEOPHISICA , S-t Petersburg, Fajansovaja N 20, RUSSIE /

La methode du champ tournant electrique conciste de mesurage de deux components du champ electrique (horisontales et ortogonales) sur la surface de la terre. L'issue du champ est deux lignes ortogonales du courant harmonique. Les phases du courant dans les lignes sont differentes a 90 degrees. Cette methode, d'apres notre modelisation mathematique se distingue des autres par les proprietees suivantes:
1. L'orientation des profiles ne depend pas de la direction des objets de recherches
2. La forme des anomalies electrique est egale a celles magnetiques quand les objets sont magnetisees en direction verticale. C'est a dire dans le cas le plus simple pour l'interpretation
3. On peut faire les installations avec les lignes du courant eloignee de l'objet de la prospection. C'est importand pendant les travaux geophisiques urbaines, quand il n'y a pas de possibilitees d'utiliser les installations classiques.
4. Theoriquement cette methode permet de resoudre la probleme inverse de la prospection electrique en 3 Dimensions.
La 3D modelisation electrique est faite avec le programme pour PC que nous avons annoncez sur la conference precedente.

A SPECTRAL OPERATOR FOR TRANSFORM VERTICAL MAGNETIC GRADIENT MAP IN A TOTAL FIELD MAP; APPLICATION TO ENVIRONMENTAL AND ARCHAEOLOGICAL PROSPECTION

N. Florsch (LEPCAT, Université de La Rochelle, Avenue Marillac, 17042 La Rochelle Cedex 1)
D. Orseau (LEPCAT, Université de La Rochelle, Avenue Marillac, 17042 La Rochelle Cedex 1)

Raw total magnetic field measurements must be corrected for time variations in order to provide interpretable data sets. To do that, a second magnetometer is used which records continuously the total field, or the data are corrected using repeated measurements at a base station at short time intervals. The latter procedure is widely used but introduce additional noise ; this constraint explains why vertical gradiometers are more and more used. Indeed, the simultaneous measurements using two probes allows to eliminate temporal change in the field. The gradiometer also provides a better spatial resolution. However, the measurement by itself leads to the loss of the low wavenumber information, which results in the reduction of the signal of deep-seated sources, while the shallow-source anomalies are magnified and sometimes may conceal the most interesting anomalies. The so-called regional anomaly is also highly damped. We focus our interest on the possibility of recovering the total field from the gradiometer measurements. The spectral operator performing this transformation is easily derived from the more classical upward and downward continuation operators. We quantify the loss of information in the spectral domain and point out the recoverable part of the total field. We show that recovering a linear trend in the total field is an « ill-defined problem », in Thikonov's sense. The theory is illustrated by a survey on a palaeo-metallurgic site at St Veran, Hautes-Alpes, France.

CONTRIBUTION OF MICROMAGNETIC MEASUREMENTS TO ARCHAEOLOGICAL INVESTIGATIONS

M. El Eraki (Geologisch-Palaeontologisches Institut, Im Neuenheimer Feld 234. 69120 Heidelberg, Germany. on leave from Geology Dept., Zagazig Univ.,Egypt).

A case example of micromagnetic survey applied to archaeological exploration is presented from the eastern part of the Tell Basta historical site, Zagazig, Egypt. Because of the presence and domination of many different civilizations in this area different archaeological objects are expected, each representing the mode of life and culture during its equivalent time.
At first, 2040 magnetic stations are measured, using the Proton Magnetometer, along 34 N-S profiles with station intervals of 0.5 m. After correcting the measured data for diurnal variation a total intensity magnetic map was prepared. Then, for enhancement of meaningful signal with respect to noise and better definition and resolution of composite anomalies, reduction to the pole (RTP) and filtering techniques were applied.
Beside the improvement of the meaningful anomaly-to-noise ratio, the results deduced from the numerical analysis and modelling of the RTP magnetic map revealed the presence of some shallow anomalies (0.5-3m depth) of archaeological interset. These are: 1) hidden subsurface walls have widths of about 2m and heights of more than 2.5m, and 2) Scattered subsurface buildings some of them circular and others elongate, probably represent kilns and tombs, respectively.

Comparative Magnetometer Surveys over the Stonehenge Avenue and Other English Sites

J. Fassbinder, Ref. Archaeolgical Prospection & Aerial Archaeology
Postfach 10 02 03, D-80076 Munchen, Germany.
A. David , M. Cole, N. Linford, P. Linford, A. Payne, Archaeometry
Branch, Ancient Monuments Laboratory, English Heritage, 23 Savile Row, London, W1X 1AB, UK.

Magnetic surveys of three archaeological sites (Stonehenge Avenue, Letcombe and Yarnton) were undertaken with both fluxgate and Caesium magnetometers to allow a qualitative comparison of the two systems to be made. The instruments used were the Geoscan FM36 fluxgate gradiometer and the CS2 Mep720, Scintrex/Picodas caesium magnetometer as used by the Archaeometry Branch of the English Heritage and the Bayerische Landesamt f. Denkmalpflege respectively.
In an attempt to produce a good overview of the potential of both techniques, archaeological sites of different periods and geologies were chosen. Two of the sites are located over chalk (Stonehenge Avenue and Letcombe) whilst the third (Yarnton) is situated over a river terrace gravel. In addition, the value of this exercise was enhanced by availability of ground truth information from excavations at two of the sites (Letcombe and Yarnton) following the surveys.
The results reveal only slight differences in the potential of these instruments but it is proposed that these might sometimes be of significance to the archaeological interpretation of the data.

THE INTEGRATED RADAR INVESTIGATION IN VALENCIAN CHURCHES: PATHOLOGIES AND ARCHAEOLOGY

V. Pérez Gracia; F. García García, J. Clapés, R. Osorio, J.O. Caselles, J. A. Canas and Ll. Pujades. Technical University of Catalonia, Barcelona (Spain).

During the last years, the Applied Geophysical Survey of the Politechnical University of Catalonia has carried out GPR investigations at cultural heritage sites in Spain. One interesting case is the integrated study of some churches in Valencia, where three different types of problems were analysed. Two problems were actual civil engineering ones, concerning the real state of the structures and their possible pathologies: humidity damages in the walls and in the floor, materials detachment and underground layers deformations due to water pressure in the clay layers and to the poor consistency of alluvial formations. The third problem, one of archaeological research, involved the search for the possible existence of other structures or older cultural layers underneath the investigated monuments. The GPR survey was applied in order to determinate the damaged area caused by humidity and to study the possible existence and the location of anomalies because of possible human constructions underneath which could affected the structure causing fissures, deformations or movements in the walls and in the roof, damaging the church structure and the paintings in fresco. GPR investigations also assists to the studies of the ancient bibliography and cartography about the monuments. It is an interesting technique for use in conjuntion with archaeological researchs or restoration jobs.

MAGNETIC SURVEY AT ZOFIPOLE, SOUTHERN POLAND

T. Herbich (Polish Centre of Mediterranean Archaeology in Cairo, 11 Mahalla st., Cairo-Heliopolis, Egypt; Institute of Archaeology and Ethnology, 00 140 Warsaw, Al. Solidarnosci 105, Poland)

The site Zofipole lies 30 km east of Krakow, at the northern edge of the Wistula river valley and southern edge of the loess part of the Krakow upland. The site was the biggest centre of pottery production in Poland during the Roman influences period (1-5 cent. AD) and belonged to the Przeworska Culture. 34 kilns were discovered during excavations carried out between 1934 and 1952. A goal of a geophysical survey was to establish a real number of kilns, an extent of the site and a proper position of the kilns excavated before 1952. The Geoscan Research fluxgate magnetometer FM36 was used. The measurements were taken at the 1 x 0.5 m grid on the area of 2.5 ha. Due to the survey, both the positions of excavated kilns were verified and at least 26 new production units were discovered. Moreover, the boundary of the site was established.
In Barbaricum, at the area north of Danube and west of Elbe, traces of pottery production were discovered at 102 sites. The geophysical survey showed that Zofipole, with a total number of at least 60 kilns, was the biggest centre of pottery production in the Central Europe in the Roman influences period.

ARCHAEOLOGICAL APPLICATIONS AND SIGNIFICANCE OF THE TEM RESULTS FROM THE CHERNORUD SITE (WESTERN PRIBAIKALJE)

N.O.Kozhevnikov and S.P.Nikiforov (State Technical University, 83, Lermontov St.,Irkutsk, 664074, Russia)
V.A.Kravchinsky (Ost Siberian Inst. for Geology, Gephysics and Minerals, 29, Dekabr'skikh Sobytiy St.,Irkutsk, 664007, Russia)

During carrying out a TEM survey at the Chernorud site on the western shore of the Lake Baikal (Western Pribaikalje) a low-resistivity anomaly was outlined over an 100m by 150m area. Since both in-situ and laboratory DC resistivity measurements didn't indicate any conductive rocks evidence within the TEM anomaly area, the TEM results seemed to be confusing.Subsequent laboratory TEM measurements on soil samples have shown slowly decaying transients to be caused not by eddy currents but by the magnetic viscosity effects which, from the hysteresis and Curie temperature analyses, have to be attributed to the relaxation of extremely fine iron and magnetite particles. At first, these particles were thought to have their origin in an meteorite event, but a closer site examination has revealed many iron age slags to be present within earth's superficial layer in the central part of the TEM anomaly area. Later some bloom remains have been also found with in- situ soil magnetic susceptibility measurements. It should be noted, however, that due to a random distribution of the slag and bloom remains no detectable magnetic anomaly there exists within the site area.

EXPERIMENTAL MAGNETOMETRIC SURVEY ON ARCHAEOLOGICAL SITES ON SIR BANI YAS ISLAND, ABU DHABI (UAE)

R.Krivanek (Institute of Archaeology of Czech Academy of Sciences, Letenska 4, CZ-118 01 Praha 1, Czech Republic)

The rescue archaeological excavation on Sir Bani Yas Island are realised under the patronage of Abu Dhabi Islands Archaeological Survey Project. For the application of geophysics during the fifth season there was decided due to dramatic changes of coastal areas by buldozing and extensive plantation where the loss of archaeological localities was increasing dramatically. Dry desert conditions together with recent irrigation system and water terminals were not optimal for resistivity survey. The efficiency of the magnetometric results was also very much limited by conditions of measuring, and in particular by the rapid artificial changes being made to the landscape, but an experimental application of magnetometric survey during archaeological excavations gave an idea about better preserved areas and eliminate destroyed parts of observed sites. It was the first simple implementation of magnetometric methods in archaeology within this area of the Gulf with its extreme climatic conditions but the results at wide pre-islamic complex of buildings of site 9.1 showed that in case of better preserved subsurface layers and low deponed archaeological features it is possible to identify in monotonous non-magnetic sandy background non-magnetic claystone or coral walls by very low positive magnetic anomalies. Success of identification is dependent only upon their state of preservation and non-presence of another higher anomalies caused by recent changes and activities.

GEOPHYSICAL SURVEY OF ABANDONED MEDIAEVAL GLASS-WORKING SITES IN NW BOHEMIA

R.Krivanek (Institute of Archaeology of Czech Academy of sciences, Letenska 4, CZ-118 01 Praha 1, Czech Republic)

The cooperation between archaeologists and geophysicists within the research of mediaeval glass-working sites in NW Bohemia has been carried out over the past 14 years. Many from these sites in the Ore and Lusatian mountains became to be threatened by wood exploration and by new afforestation. Magnetometric prospection acompained by field ground survey seemed to be the best method for quick identification of ancient features. During that long time more than 40 areas of 23 sites (17 in Bohemia and 6 in Germany) have been surveyed by geophysics. Systematic excavations have been carried out at 8 localities. Magnetometric survey identified about 30 glass-furnances, 5 glass-waste heaps and some other archeological features. The magnetometric data from individual sites very often share a similar character. Therefore was possible to summarize the results within a types, amplitudes and the average surface extent of positive magnetic anomalies. The glass-furnances have a very significant positive magnetic anomaly within a very limited area and negative border around. Glass-furnances are very often in triangular geometry within one main and two smaller furnaces for cooling. The glass-waste heaps are represented by wide positive unhomogenous magnetic anomaly. Other archaeolgical features containing no burnt materials have lower positive magnetic anomalies. Using magnetometry in this particular field before excavations will be planned as a necessary component of any field project concerning deserted mediaeval glass-working sites.

APPLICATION OF MAGNETOMETRY IN VERIFICATION OF AREIAL PHOTOGRAPHY IN BOHEMIA

R.Krivanek (Institute of Archaeology of Czech Academy of sciences, Letenska 4, CZ-118 01 Praha 1, Czech Republic)

A systematic cooperation between geophysics and aerial prospection has been carried out in Bohemian archaeology since the 1990s. Because both of these non-destructive methods use different scales of survey and different principles of data collection the aims of methods are not the same. Aerial photography is normally used more less for a systematic evidence of archaeological sites. Geophysics is not necessary and real to apply on each from these discovered sites. Geophysics in Bohemia is used in special cases of archaeological interest and questions, for quick and more precize documentation of threatened sites and their potential protection. Magnetometry seemed to be the most efficient method for the verification of result of aerial photography in open not recently settled landscape. The results for example showed that by magnetometric survey we could not only identify ploughed relicts of prehistoric tombs but also separate different fillings of central graves as on nortbohemian site Cernoucek. Another very good experience we had from magnetometric surveys of hillforts documented by aerial prospection. Magnetometry helped identify real type of fortification with burned materials inside of wide rampart and two paralel outside ditches on Hallstatt and Early Mediaeval hillfort by Prerov n.L. in central Bohemia. Magnetometric survey of wide Early Mediaeval hillfort in centralbohemian Tismice verified internal divisions by ditches and discovered ploughed entrance to the central part.

STRUCTURES AND FORTIFICATION OF THE LOWER TOWN OF NESTOR'S PALACE, PYLOS, GREECE, DETECTED BY DIFFERENT GEOPHYSICAL METHODS

F.K. Kuhnke, F.C. Fieberg (Institut für Geophysik und Meteorologie, TU-Braunschweig, Mendelssohnstr. 3, D-38106 Braunschweig, Germany) E. Zangger (Geoarchäologische Rekonstruktionen, Fliederstraße 21, CH-8006 Zürich, Switzerland)

During two weeks in July '95 we covered almost 10.000 square meters southwest of Nestor's Palace, Pylos, Greece, with three geophysical prospecting methods: magnetometry, with an Overhauser gradiometer and a fluxgate instrument for the vertical gradient of the earth's magnetic field; electromagnetometry, with a ground conductivity meter, and resistivity with manual and/or automatic earth resistance meters in Wenner and Dipol-Dipol configuration.
The results of all different measurements will be presented and discussed. The measurements with respect to the apparent resistivity are effected by the olive trees on the surveyed ground, whereas all magnetic readings are free of such influences. Despite this, all results show a good agreement. – The strongest anomaly can be seen in both magnetic and resistivity records. So far it is a sixty-meter long lineament at least two meters wide. It might reflect the remains of a massive, thus far unsuspected defense wall around the Palace of Nestor.

DETERMINATION OF THE MAGNETIC MINERALOGY AND THEORETICAL MAGNETOMETER RESPONSE FROM AN ANGLO-SAXON BUILDING AT YARNTON, OXFORDSHIRE, ENGLAND

N. Linford (Archaeometry Branch, Ancient Monuments Laboratory, English Heritage, 23 Savile Row, London W1X 1AB, UK)

Following recent commercial extraction of sand and gravel underlying agricultural land close to the village of Yarnton, Oxfordshire, England, a plethora of archaeological features from the early/mid-Neolithic to the medieval period have been discovered. Aerial photography identified a possible Anglo-Saxon building that has recently been evaluated by a programme of surface artefact recovery, geophysical survey and subsequent excavation. The geophysical survey involved the collection of both vertical gradiometer data with a Geoscan FM36 and total magnetic field strength measured by a Scintrex caesium vapour magnetometer. During the subsequent excavation a number of samples were recovered from the buried archaeological features and n atural subsoil to which a suite of magnetic measurements were applied. These included low field susceptibility, isothermal remanence and the determination of hysteresis parameters from in-field measurements made with a vi brating sample magnetometer. Analysis of this data was used to indicate the likely magnetic mineralogy of the samples and establish the volume susceptibility contrast between the archaeological features and subsoil. Theoretical responses were then calculated for the two classes of magnetometer and compared with the recorded field data.

GEOPHYSICAL PROSPECTION OF ARCHAEOLOGICAL STRUCTURES IN POTSDAM

E. Lück, (GFZ Potsdam, Telegrafenberg, D-14473Potsdam, Germany: erika@gfz-potsdam.dc)
M. Eisenreich, U. Spangenberg (Universität Potsdam)

Geophysical investigations of archaeological structures inside a town demand an extremly high resolution for the data. Signals from modern objects are much more higher than signals from older structures. Because of the spatial limitation sometimes it is difficult to get information about deeper objects.
There were tested varios methods to research two sites in Potsdam. So it was possible to detect the location of two ditches arround the oldest place of the town and to research the foundations of some old buildings like the church 'Heilig-Geist'and the former castle. Especially resistivity methods were usefull. Many pseudosections (Wenner- and dipol-dipol-arrays) were measured and inverted.
In addition magnetic and electromagnetic prospections were used to get different maps which give an overview about invisible objects within the subsoil.

LOCALIZATION OF ARCHITECTURAL REMAINS INSIDE BUILDINGS BY ELECTRICAL AND ELECTROMAGNETICAL MEASUREMENTS

Krzysztof Misiewicz (Instytut Archeologii i Etnologii, Polska Akademia Nauk, Al. Solidarnosci 105, 00-140 Warszawa, Poland)

Examples of undestructive geoelectrical measurements combine with GPR prospection made for localization of architectural remains are presented here. The remains - foundation of stone walls mixed with red-bricks, unknown funeral cavities, underground passages- were situated beneath the pavement of still existing medieval churches. Geoelectrical measurements and GPR prospection were emplyed for exact localization of preserved stuctures. System of contact electrodes used both as the current and potential probes allows to employ standard geoelectrical instruments for taking the measurements. Results of surveys carried out at St. John Cathedral, St. Catherine Church in Warsaw and Holy Mary Church in Poznan illustrate the possibilities of using in prospection the different systems of geoelectrical mesurements - Symetrical, Middle Gradient profiling and Geoelectrical Vertical Sounding. Comparision of the exactitude of measurements of resistivity made with different systems in the same geological conditions give a chance of choosing the most effective method of survey. Combining geoelectrical prospection with GPR survey allows to collect the additional data for interpratation of the result obtained by using of the both methods of prospecting. Such combination let us also to compare the efficiency of two different geophysical method used, in presented cases, in extremely difficult conditions.

RESISITIVITY AND MAGNETICS OF THE ROMAN TOWN CARNUNTUM

W. NEUBAUER (University of Vienna, IDEA, Dpt. f. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Vienna, Wolfgang.Neubauer@univie.ac.at)
A. EDER-HINTERLEITNER (Vienna University of Technology, Institute for Automation, Pattern Recognition and Image Processing Group, Treitlstrasse 3, A-1040 Vienna, ahi@prip.tuwien.ac.at)

In the best known Roman town Carnuntum in the Eastern part of Austria systematic geophysical prospection has started. In the civil town, former residence of Emperor Marcus Aurelius, a five hectar area was prospected by resistivity and magnetics. The results of the first survey show the lay out of the town, i.e. roads and insulae. An unexplored part of the Roman town at the river danube is now recovered, bringing up a lot of archaeological information on the hitherto unknown archaeological area.

3D-INTERPRETATION OF POSTPROCESSED ARCHAEOLOGICAL MAGNETIC PROSPECTION DATA

W. NEUBAUER (University of Vienna, IDEA, Dpt. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Vienna, Wolfgang.Neubauer@univie.ac.at)
A. EDER-HINTERLEITNER (Vienna University of Technology, Institute for Automation, Pattern Recognition and Image Processing Group, Treitlstrasse 3, A-1040 Vienna, ahi@prip.tuwien.ac.at)

Magnetic surveys carried out with an automatic Caesium Gradiometer in the 1980s suffer of systematic and unsystematic data errors. Recently developed algorithms for restoring erroneous magnetic data allow postprocessing of the early surveys. The restored data are tereafter suitable for a 3D-modelling algorithm. The 3D-output of the algorithm is used for 3D-interpretation and reconstruction of the monument. The processing is demonstrated for a circular ditch system dating from the Middle Neolithic period about 6800 BP at Strögen/Austria.

COMBINED INTERPRETATION OF MAGNETIC AND RESISITIVITY SURVEYS ON ROMAN SITES

W. NEUBAUER (University of Vienna, IDEA, Dpt. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Vienna, Wolfgang.Neubauer@univie.ac.at)

Magnetic and resisitvity surveys are the most successful geophysical prospection techniques for archaeological purposes. Magnetics carried out with an automatic Caesium Gradiometer recover ditches, pits, ovens, bricks, wooden palisades etc. very clearly. On the other hand the walls of roman buildings usually are only fairly resolved in magnetics. Often they are covered by large anomalies of bricks and tiles in and around the buildings. An additional resitivity survey points out the walls or floors, stony features in general. Resistivity is three times as time consuming as magnetics for half the spatial resolution and is therefore applied on detail areas only, derived from the interpretation of the magnetogram. Resisitivity and magnetics are overlayed as transparent, multiplied or subtracted digital images for a combined archaeological interpretation in a GIS.

COMBINED USE OF ELECTROSTATIC AND GPR FOR THE SURVEY OF THE BASEMENT OF STANDING MONUMENTS

C.Panissod, M. Dabas (Centre de Recherches Géophysiques, Garchy, 58150 Pouilly sur Loire)
C.Camerlynck (Université Paris VI, Dpt. de Géophysique Appliquée, Tour 15-25, Boite 105, 75252 Paris Cedex 05)

The search for the foundations of previous buildings in historical monuments has to face difficult problems encountered in every urban area: a difficult access to any free surface for investigation, a strong electromagnetic noise and a complexity of the subsurface which is rarely encountered outside the historical centers of the cities. Despite these problems, there is a growing need for a non-destructive investigation of historical buildings and especially their foundations. Ground Penetrating radar (GPR) and electrostatic (ES) surveying have proved to be successfull and complementary. The lateral variations of resistivity can be pictured with an electrostatic device without any direct galvanic contact with the ground. The vertical variations are pictured by a processing of GPR data (time slices). Two sites were studied with both technics: the abbey of Saint Germain d'Auxerre(Frannce) and the cathedral of Warszawa (Poland). Several buried structures were located both vertically and in their lateral extension. GPR data (reflectivity as a fonction of the contrast in permittivity) and ES data (resisitivity) often proved to be similar. We think that a common physical parameter plays a major role and this could be the water content of the investigated area.

HIGH RESOLUTION GEOPHYSICAL PROSPECTING WITH INTEGRATED METHODS. THE CASE OF ANCIENT ACROPOLIS OF VEIO (ROME, ITALY).

F. Cammarano, S. Piro and F. Rosso (ITABC, CNR, P.O. Box 10, 00016 Monterotondo St. (Roma, Italy).
P. Mauriello (Dip. Geofisica e Vulcanologia, Univ. Federico II, Napoli, Italy).

Generally it is difficult to apply geophysical methods to detect small subsurface features, especially when the structures are made with the same materials of the ground. In this case we obtain a low value of the signal-to-noise ratio. The geophysical fundamental goal in near-surface investigations and environmental applications is to construct as complete as possible maps of subsurface targets. The main effort in archaeology is the integration of different, absolutely non-invasive techniques which must operate according to the principle of potential correlation among all the methods. In the present work a combination of gradiometric (Geoscan FM36), GPR (SIR 10, 500MHz antenna) and dipole-dipole geoelectric methods has been employed with the aim of detecting superficial structures (wall-remains and traces of ancient road) contained in an archaeological test area (Ancient Acropolis of Veio, Rome). The selected test area, which probably contain the archaeological structures, has dimensions of 20 m x 20 m. For all profiles, measurements have been carried out at regular grid interval of 0.5 m. Some signal processing and tomographyc representation techniques have been used for the elaboration and interpretation. The results of the geophysical surveys have been confirmed by direct archaeological excavations carried out only at anomalous zones.

COMPARATIVE STUDY OF MAGNETOMETER RESULTS FROM A KILN SITE NEAR OOTO, JAPAN

A. Schmidt (Department of Archaeological Sciences, University of Bradford, Bradford BD7 1DP, U.K.)
H. Kamei (Tokyo Institute of Technology, 2-12-1, OOOKayama, Meguro, Tokyo 152, Japan)
Y. Nishimura (Nara National Cultural Properties Research Institute, 9-1-2 Nijo-cho Nara-shi 630, Japan)

The measurement of magnetic anomalies, caused by buried features, is a common investigation method in archaeological prospection. Various sensor types and configurations can be employed in the field (total field sensors, vector sensors, single sensors, gradiometers,...) but due to the magnetostatic nature of anomalies all results should be mathematically equivalent. This paper will examine the theoretical relationship of three datasets that were recorded at an ancient kiln site near Ooto, Japan. Measurements were made with a proton magnetometer (using a fixed base station), a fluxgate vertical component gradiometer and a three axis (vector) fluxgate gradiometer. Data are converted to a common reference representation and compared with each other

DETERMINATION OF SPATIAL ORIENTATION OF MAGNETIC ANOMALIES USING BIDIMENSIONAL CROSS-CORRELATION TECHNIQUE.

S. Piro and L. Versino (ITABC-CNR, P.O. Box, 10, 00016 Monterotondo St., Roma, Italy).

Locating shallow bodies of archaeological interest by the application of various geophysical methods is now satisfactorily established. Different techniques for processing of field data are presented by many authors which are mainly applied either for improving S/N ratio or resolution of modest anomalies due to interfering effects. This problem is critical in the case of subsurface investigations in archaeological sites when generally the anomalies are very small. This is also the case in a magnetic survey when the susceptibility contrast is not pronounced. In this paper we deem to present an attempt for delineation of the spatial orientation of subsurface magnetic anomalous bodies. In order to obtain the enhancement of the signal-to-noise ratio the bidimensional cross-correlation technique has been used. To apply this technique, theoretical magnetic anomalies due to a synthetic model having the same dimensions as the one searched and due to a anomalous body with small dimensions (1x1x1 grid units) have been calculated (gradient of vertical magnetic component). A synthesis of some of these calculated curves is presented. Comparison of the results of application of the two serie of calculated anomalies are presented both for theoretical and field data sets.

Experience with magnetic prospecting in the process of rescue archeology on Hungarian motorways

Sándor Puszta (Lorand Eötvös University, Geophysical Department, H-1083 Budapest, Ludovika tér 2. Hungary)
Pál Raczky (Lorand Eötvös University, Archeological Institut, H-1088 Budapest, Múzeum krt. 4/b. Hungary)

Maps were made for rescue archeology on Hungarian motorways based on near 1 million measured points on surface. Measurements were accomplished by a 0.1 nT resolution proton magnetometer. Collected data were preprocessed by signal enhancing methods. Both deterministic filters (reduction to the pole, downward continuation, and filters depending on radial frequency or direction) and stochastic filters (optimal smoothing) have been used. Applied parameters essentially influenced the quality of the obtained maps. The magnetic prospecting results were then compared to the computerized results of the excavation. The successful correlation makes it possible to know the extension and structure of the unexcavated settlements. By previous geophysical activities the archeological excavating works can be planned and this means an economic advantage.

APPLICATION OF SEISMIC AND GEOELECTRICAL SOUNDING IN ARCHAEOLOGICAL PROSPECTION

S. SEREN (Central Institute for Meteorolgy and Geodynamics, Dpt. f. Geophysics, Hohe Warte 38, A-1190 Vienna, sirri@zamg.ac.at)
W. NEUBAUER (University of Vienna, IDEA, Dpt. f. Geophysical Prospection, Franz Kleingasse 1, A- 1190 Vienna, Wolfgang.Neubauer@univie.ac.at)

Resistivity and high resolution magnetic surveys on iron age hillsites are not easily to interpret because of near surface geological features. Conglomerats of habitations inside the fortified oppidum in Schwarzenbach, Austria (3.-1-Century B.C.) were easily detectable by magnetics and resistivity. Detail areas and single profiles were thereafter selected for seismic and electrical soundings to exclude geological features from archaeological interpretation. A small plateau showing anomalies of a building and surrounding ovens in magnetics and resisitivity was selected for a 3D seismic mapping approach to give preliminary indications on layer thickness, geological background and additional information on the known archaeological structures before excavation.

COMPLEX GEOPHYSICAL INVESTIGATONS FOR STUDYING CULTURAL LAYER AND REMAINS OF ANCIENT BUILDINGS ON THE TERRITORY OF THE KAZAN KREMLIN, KAZAN, REPUBLIC OF TATARSTAN, RUSSIA.

Z.M.Slepak (Geological Faculty, Kazan University, 18 Lenin St, Kazan 420008, Russia)
G.M.Tregubovich (Siberian Research Institute of Geology, Geophysics and Mineral Resources, 67 Krasni Pr., Novosibirsk 630104, Russia)

Architectural ensemble of the Kazan Kremlin bears marks of different epochs,- from VII-VI centuries BC to the Russian period (XVI-XIX). Geophysical studies are to solve the problems of archaeology and engineering geology, and include electro-magnetic sounding and high-precision"profile-area"gravity prospecting with precision of Bouguer anomalies being as high as 10×10^{-8} m/s^2, — enough to reveal, using maps and profiles, local gravity changes associated with the sought-for objects. For electro-magnetic sounding, equipment permitting to record,- during both discrete and continuous measurements,- field's stabilization at super-early times was used. High density of space-and-time field's recording permitted layer-after-layer study of the section using sections and maps of electrical conductivity for certain depths. Complex interpretation of geophysical data resulted in revealing a surface associated with the bottom of a cultural layer as well as changeability of physical fields for both known and supposed remains. Subsequent archaeological excavations confirmed the gravimetric data that detected the remains of stone constructions within the cultural layer.

MAGNETIC INVESTIGATIONS OF IRON-PRODUCTION CENTERS WITH SLAG-PITS IN SOUTH-WEST JUTLAND

O.Voss (National Museum, Copenhagen, Denmark),
N.Abrahamsen, Ph. de Lasson (Aarhus University, Denmark),
U.Koppelt (Leipzig University, Germany),
T.Smekalova (Physics Institute of Saint-Petersburg University, Russia)

The investigations in South-West Jutland, where the great concentration of iron-smelting sites with slag-pits is known, were continued in 1996. In 1992-1995 a big iron-production site Snorup (about 35 ha and 4000 slag-pits) was investigated by magnetic prospection. The works of 1996 were devoted to revealing and magnetic mapping of the closest sites, for solving the question about the structure of the net of iron-production centers in this metallurgical region in Late Roman Time. At Krarup (6 kms to the East from Snorup) the investigations, which started on a limited areas in 1994 and 1995 were continued, and a big territory of iron-production center was investigated by the method of "free search" and than by the detail magnetic measurements on chosen areas. The combination of these methods allowed to completely surveyed the whole center, in spite of its considerable area (6 ha) and to reveal more than 600 slag-blocks. At Yderik (3.5 kms to the South from Snorup) several hectares were investigated revealing more than 500 slag-blocks. At Horne (2 kms to the West from Snorup) a wide strong anomaly of the value more than 350 nT corresponds to some structure of burned clay and peaces of slag, as the test excavations shown.

THE ROMAN VILLA OF KIRCHBERG/STEINACKER: AN INTEGRATED GEOPHYSICAL SURVEY

J.J.M. Wippern and S. Jenter (Rheinisches Amt f. Bodendenkmalpflege/Landschaftsverband Rheinland, Endenicher Str. 133, D-53115 Bonn)

The site of Kirchberg/Steinacker is situated in the run-up to the open-cast mining Inden I in the Rhineland. Fieldwalking established the presence of a relatively large Roman villa rustica here. However, this method did not yield in adequate information either about the exact location or the preservation of interesting archaeological features. Therefore, an integrated geophysical survey was carried out using two different fluxgate gradiometer systems and a resistivity meter in twin configuration. Especially the results of the resistivity measurements were good: even the position of several column foundations could be located.

SE14 Near-surface geophysics: archaeological prospection and archaeomagnetic dating

Conveners: Faßbinder, J.; Hoffmann, V.

02 Archaeomagnetic dating

Convener: Abrahamsen, N.
Co-Convener: Pesonen, L.J.

ARCHAEOMAGNETIC SURVEY, DATING & PALEOINTENSITY OF MEDIEVAL TILE KILN AT KUNGAHÄLLA, SW SWEDEN.

P. Riisager, N. Abrahamsen (Dept. of Earth Sciences, Aarhus University, Finlandsgade 8, DK-8200 Aarhus N, Denmark. E-mail: geofabe@aau.dk) & A. Smirnov (Earth Physics Dept., Inst. of Physics, St.-Petersburg University, 1 Ul'anovskaya, St.Petergoff, 198904 St.-Petersburg, Russia)

A case history is presented, using magnetic methods for detection, dating and paleointensity studies of the remains of a medieval tile kiln, situated at Kastellegården in Kungahälla, some 20 km NNE of Gothenburg in Sweden (57.9^0 N, 12^0 E). After thermal and AF cleaning procedures on *in situ* oriented bricks, a stable mean direction of the ChRM was found to be (D_m, I_m) =(8.8^0, 66.7^0), (α_{95}=1.7^0, N=12, k=655). Comparing with the archaeomagnetic British mastercurve for secular variation (Clark et al., 1988), transformed by a geocentral dipole-transformation from Meriden (UK) to Kungahälla in Sweden (a distance of 1000 km), a magnetic date of either 1300±40 or 1500±40 AD could be obtained. Comparing these dates with a TL-date of 1360±40 AD (V. Mejdahl, personal comm.) as well as by historical and archaeological evidence (J. Rytter, personal comm.) about a related Franciscan monastery known from 1277 AD, the older magnetic dating of 1300±40 AD is supported.

A paleointensity study, using the Thellier-Thellier and the step-by-step remagnetization methods (Shashkanov & Metallova 1977), gave almost the same results (Thellier: F=70.9±3.2 μT, N=7; step-by-step: F=65.8±1.0 μT, N=4, respectively), indicating a local geomagnetic paleointensity of ~68 μT.

MAGNETIC INVESTIGATIONS AND DATINGS OF A BRICK KILN AT VELDBÆK NEAR ESBJERG, SW DENMARK.

N. Abrahamsen, U. Jacobsen, & V. Mejdahl (Dept. of Earth Sciences, Aarhus University, DK-8200 Århus N, Denmark. E-mail: geofabe@aau.dk) and U. Mejdahl (Esbjerg Museum, Norregade 25, DK-6700 Esbjerg, Denmark)

Detailed magnetic total field and gradient measurements over remnants of a tile kiln at Veldbæk (55.46°N, 8.50°E) near Esbjerg in SW-Jutland (Denmark) show magnetic anomalies of up to 200 nT. Although poorly preserved the anomalies revealed the rectangular shape of the kiln as well as specifically depicted the heating channels. The bulk susceptibility of the soil showed markedly increased values at the kiln-area as compared to the surrounding uncontaminated smelt-water sands.

After thermal and AF cleaning the remanent magnetisation of *in situ* specimens from the kiln floor gave a directionally very stable ChRM with a mean direction of (D_m, I_m) = (331°, 73.7°), (α_{95}=2.0°, N=39, k= 131). Comparing with the British mastercurve for secular variation (Clark et al., 1988), transformed by a geocentral dipole-transformation from Meriden (UK) to Esbjerg (55.5° N, 8.5° E), the last time of heating/cooling may be dated to 1790 ±40 AD. Although at first in conflict with earlier expectations, the magnetic age is supported by an OSL date of 1795±20 AD, and by renewed historical studies, which show an increased building activity in the area, as bricks were used in a building boom during agricultural reforms 1790-1810.

ARCHEOMAGNETIC INTENSITY RESULTS FROM FRANCE

Garcia Y. (CNRS UMR 153 and Geosciences Rennes,35042 Rennes Cedex France), A.Chauvin (Geosciences Rennes, CNRS UPR 4661, 35042 Rennes France email: Annick.Chauvin@univ-rennes1.fr) and Ph. Lanos (CNRS UMR 153, 35042 Rennes Cedex France)

Very few results of archeomagnetic intensity in France are available. The intensity of the geomagnetic field was determined on 21 archeological sites from southern and western France using the Thellier technique on six to 12 samples per site. Almost all the archeomagnetic materials studied are characterized by low unblocking temperatures, evenly distributed between 100 and 550!C. Cooling rate effects upon the TRM intensity have been investigated and the paleointensities were corrected. AMS and TRM anisotropy tensors were determined on each sample. If the direction of the principal axes of both tensors are usually identical, no clear relationship was found between the intensity of the eigenvalues of AMS and TRM tensors. This result limits seriously the use of AMS anisotropy to correct archeomagnetic results. The degrees of TRM anisotropy observed are typically around 25% and could reach high values (up to 80%). Thus TRM anisotropy data are used to provide an unbiaised paleointensity value. Paleointensity results with an analytical error typically lower than 10% are obtained for two times intervals. During the roman period (between 20 - 410 AD) the strength of the magnetic field at Paris is close to 65 micro Tesla with a maximum value of 70 mT while between 1300-1730 AD the field intensity decreases from 60 to 50 micro Tesla.

DETECTION OF MAGNETIC ANOMALIES OF RANDOM HETEROGENEOUS ARCHAEOLOGICAL OBJECTS

M.Cucarzi (Fondazione Ing. Carlo M.Lerici, Roma, Italy)
N.N.Efimova and V.V.Glazounov (Department of Geophysics, State Saint-Petersburg Mining Institute (Technical University), Russia)

Typical archaeological objects which have random heterogeneous structure are remains of brick buildings. Their heterogeneous structuris determinates by TRM of bricks. Directions of the vector Jrt depend on orientation of bricks inside the walls of building and pottery kiln during burning. At least 4 variants of vector Jrt directions are possible. Magnetic field ΔT remain of brick foundations as physico-mathematical modeling showed is characterizsized by intensive distribution. Structure of magnetic field ΔT is due to deterministic ΔTd and random ΔTr components. Magnetic field ΔTd is effect by vector induced magnetization Ji and field ΔTr- by vectors of Jrt of bricks. Since Jrt>>Ji the observated magnetic field ΔT of brick foundation is almost totaly determinated by the random component ΔT≈ΔTr. Therefore to detect of archaeological objects with random heterogeneous structure on base of magnetic field ΔT, it is nessecary to use numerical filters which are tuned for analysis of field distribution. Theoretical foundation and calculation althorisms of synthesis of optimal and quazyoptimal filters for detection of field of brick foundation are studied. Theoretical and practical examples of detection of geophysical effects of remain of brick Induist's temples of Laos are considered

WHERE TO DRAW THE LINE?
THE CALIBRATION OF ARCHAEOMAGNETIC DATES

C. M. Batt (Department of Archaeological Sciences, University of Bradford, Bradford, BD7 1DP, UK)

It has long been acknowledged that an archaeomagnetic date is only as reliable as the calibration curve from which it is derived. However, until recently, objective approaches to the construction of calibration curves for a particular region have been restricted by lack of data.
This paper examines the ways in which calibration is carried out in different regions and discusses limitations and deficiencies of the methods used. Particular emphasis is placed on archaeomagnetic dating procedures in Britain. A different approach to calibration is proposed which draws on recent advances in this subject in the USA, in particular the use of a weighted moving window method of averaging. The main advantage of this method is shown to be its ability to take into account uncertainties in both the magnetic direction and the archaeological date of data used in the calibration curve, leading to a secular variation curve with an associated error estimate. Hence, when dating a magnetic direction, the uncertainties in the calibration curve can be taken into account, as well as the uncertainties in the magnetic direction to be dated. The implications of changes in the process of calibration of archaeomagnetic dates are discussed using case-study examples.

A NEW APPROACH TO ARHEOMAGNETIC STUDY OF THE POTTERY KILNS ON THE BASE OF MAGNETOMETRIC DATA

V.V.Glazounov (Department of Geophysics, State Saint-Petersburg Mining Institute (Technical University), Russia)

Traditionally archaeomagnetic study of pottery kilns is based on collection and analysis of oriented samples. Latest archaeomagnetic study (D.H.Tarling, 1986; N.Abrahamsen, 1993) showed that the direction of vector TRM of the samples is characterizied by large scatter. Mathematical modeling of a pottery kiln magnetic structure which was done with calculation of effect of demagnetization of kiln elements in moment when TRM vector is formed allow to explain a reason of scatter-effect. Calculation showed that scatter of the vectors TRM of model is not similar to Fisher's distribution. Elements of vector of ancient geomagnetic field Trt can be estimated using vector of magnetic moment M of an object. As the direction of vector M does not almost decline from the direction of vector Trt. Methods of vector M determination are well known in theory of inverse physico-mathematical problems. On base of this methods calculation algorithms providing integlal, approximated and spectral methods were done. Algorithms work on base of information about geometry of an object, distribution of magnetic susceptibility and factor Q inside object volume. This information is avaliable after exavation of the object. Example of practical test of spectral method for medieval pottery kiln (Mountainous Crimea) dating is shown.

STATISTICAL ANALYSIS OF THE ARCHAEOMAGNETIC WORLD DATA ; SMOOTHING OF THE SECULAR VARIATION CURVES.

M. Le Goff and L. Daly. Laboratoire de Géomagnétisme et de Paléomagnétisme. CNRS, IPGP, 4 Av. de Neptune, 94107 Saint-Maur Cedex, France.

In order to obtain the smoothed values at regular time intervals of the geomagnetic secular variation, the original archaeomagnetic data have been sorted according to geographical regions, reduced to sites associated with each region, and finaly processed using the Gaussian statistic for the intensity (F) data and the bivariate statistic for the declination (D) and inclination (I) data. A discussion of these statistical methods is given. The results concern only the last 20 centuries because the archaeomagnetic data alone do not allow to go back further in the past. Archaeomagnetic studies at world sites where the number of data is not sufficient to perform a statistical analysis have also been excluded. These results are now available at 10 world sites (Arizona, Arkansas, Bulgaria, Caucasus, England, France, Hungary, Japan, Meso-America, Ukraine) for which the values of at least 2 of the three above quoted parameters have been calculated at 25 year intervals from the beginning of our Era. The results for each world site include their associated errors which are of prior interest to achieve stochastic analysis of the global terrestrial magnetic field (TMF) during the past 20 centuries.

THE SECULAR VARIATION OF THE DIRECTION OF THE GEOMAGNETIC FIELD IN POST-ROMAN TIMES IN BELGIUM

J. Hus and R. Geeraerts (Centre de Physique du Globe, 5670 Dourbes, Belgium)

About 80 fired structures, mainly kilns, ovens, fireplaces and burnt occupation levels in about 30 archaeological sites were sampled (the number of independently oriented samples varies between 8 and 104 with an average of about 30 per site) in order to establish secular variation (SV) curves of the direction of the geomagnetic field in post-roman times in Belgium. All the sites fall within the area between latitudes 48°N and 57°N and longitudes of 6°W and 9.5°E defined by Tarling and Dobson in 1995 to construct the British SV master curves. Hence our dated examined sites may contribute to refine the latter. However, it is indicated to establish independently SV master curves for a more limited area centred at Brussels as reference location. The measurements of about half of the baked structures are finished and the Bauer diagram of the inclination/declination values after correction are compared with the diagrams available for Meriden and Paris after transposition to Brussels. All the samples examined were oriented to true North with theodolite, their remanence measured in a big sample magnetometer and "cleaned" in alternating fields. Great attention was paid to large regular and irregular deviations in direction noticed in some kilns especially when recuperated baked materials, such as bricks, were used for their construction. The comparison between archaeomagnetic data and direct observations of the field since the 16th century is not always obvious because of an increase of magnetic disturbances of man-made origin in the more recent archaeological sites.

ARCHAEOMAGNETIC DATA FROM MACEDONIAN KILNS (N.GREECE)

M.E. Evans (Inst. of Geophysics, Univ. of Alberta, Edmonton T6G 2J1, CA)
D.P. Kondopoulou (Geophysical Lab., Univ. of Thessaloniki, 54006, GR)
V.S.Spatharas (Geophysical Inst., Bulg. Acad. of Sciences, Sofia, BG)

Archaeomagnetic investigations at several sites in Greece are now establishing a significant data base. In 1995 , a number of fired structures in archaeological sites of N. Greece have been investigated. Eight of them, mostly kilns, have been sampled by standard techniques, and directional measurements are reported here. The date range is classical to post Byzantine (300 BC - 1500 AD). Remanent magnetization vectors were determined by Schonsted and Molspin magnetometers and magnetic stability was tested by progressive alternating field demagnetization .
The results obtained show a satisfactory accuracy (a_{95} < 3) and can be classified as follows:
1) Classical and Hellenistic: (Europos EV, Pella PE)
2) Roman and Byzantine (Agora AL, Louloudia1,2 LC, LM)
3) Byzantine and Early - post Byzantine (Thess. 1,2,3, DI, TH, MO)
Comparison with known results for Greece and Bulgaria shows satisfactory agreement in most cases. An intensity result from one site (DI) allowed the dating of the structure at 820 - 870 AD.

MAGNETIC FIELD MODELLING OF STRONGLY MAGNETIZED BODIES

U. Koppelt(Leipzig University, Inst. of Geophysics & Geology, Talstr. 35, D-04103 Leipzig), N. Abrahamsen (Aarhus University, Geophysical Laboratory, Filandsgade 8, DK–8200 Aarhus) O. Voss (National Museum, Frederiksholm Kanal 12, DK-1220 Copenhagen)

During a five-years geomagnetic investigation at different iron-production sites near Varde in SW Jutland several thousand slag bodies that remained after the smeltings were located. In 1995/96 micromagnetic measurements with a grid step of 0.25 m were carried out over seven slag bodies. The data were inverted to determine the direction of the remanent magnetization. After excavation, these bodies were drilled. Palaeomagnetic and petromagnetic investigations were carried out for the purpose of archaeomagnetic dating. The determined palaeo field directions were quite scattered. Therefore, a numerical modelling of the field distribution of a strongly magnetized slag like body was initiated.

With the aid of an integral equation technique the effect of magnetic refraction and the resulting disturbances of field directions inside and in the vincinity of the slag body were modelled. The results explained several features found during the field and laboratory investigations, such as the mean direction pattern of the specimens and compass directions measured on top of the bodies. Moreover, they could be used to correct the results of magnetic surface data inversion.

NECESSARY CONDITIONS FOR ARCHAEOMAGNETIC DATING

Mary Kovacheva, Geophysical Institute, 1113 Sofia, Bulgaria

The accumulation of archaeomagnetic data for a particular area aims to the construction of the geomagnetic secular variation curves. The revised, supplemented and smooth results of ancient inclination, declination and intensity variations over the last 8000 years in Southeastern Europe (Bulgaria) will be shown. The dating and experimental imprecisions are taken into account in the algorithm for calculation of the among sites averages. The main difficulties for the master curves elaboration will be briefly stated
The archaeomagnetic scale of time as expressed in the above mentioned master curves of geomagnetic field elements variations can be used for dating purposes. The necessary conditions for a successful dating are summarized. Several examples from the practice in Bulgaria will be demonstrated, including the cases from the recent and prehistoric past. The necessity of both directional and intensity variation curves for a successful dating is proved from our experience, which underlines the need of a long preliminary archaeomagnetic research in the corresponding geographical region.

SOME INTERESTING REMARKS ON THE GREEK ARCHAEOMAGNETIC INTENSITY CURVE

I.Liritzis (Academy of Athens, Research Center for Astronomy and Applied Mathematics, 14 Anagnostopoulou str., Athens 106 73, Greece)

The Greek archaeomagnetic intensity (AI) curve has been compiled from archaeological ceramics, bricks, tiles, burnt clays, of the past 9,000 years from data by various authors (mainly Aitken, Kovacheva, Liritzis, Thomas, Walton). The thermal and alternated current demagnetization methods of Thellier and Shaw have been employed, following stringent reliability criteria. The current status of AI is critically considered regarding: 1) the past 1500 years variation of AI measurements made on Greek Byzantine churches dated by epigraphy, 2) the comparison of AI with palaeomagnetic intensity (PI) from lake Windermer, Britain, after appropriate time conversion scales. 3) the spectrum analysis of AI and PI, and comparison of their periodicities. Remarks are drawn concerning a) the real phenomenon of short-term drastic changes in geomagnetic variation, b) the archaeomagnetic dating implications, c) the mantle-core interaction and possible nature of non-dipole sources in the outer core, d) the question of palaeoclimatic or true geomagnetic origin of PI variation.

THE CHARACTER OF CHANGE OF THE GEMAGNETIC FIELD INTENSITY IN THE VI-V MILLENNIUM B.C.

K.S.Burakov and I.E.Nachasova (United Institute of Physics of the Earth RAN, Russia, 123810,Moscow,B.Gruzinskaja,10)

An archaeomagnetic study of ceramic material from a multilayer monuments of northern Mesopotamia Tell-Sotto and Jarimtepe II, was carried out. In the first half of the sixth millennium BC, geomagnetic field intensity was of relatively stable values with an average 48 mkT. In the period, dated as the end of the sixth millenium BC to the beginning of the fifth millenium B.C., archaeointensity was about 50 mkT. After this, a decrease in the field intensity took place to average level about of 35 mkT. Analysis of the obtained series showed, that the picture f variations in geomagnetic field intensity can be represented as the result of a summation of several quasi-periodic variations with durations from several centuries to several decades with amplitudes 2.5-0.7 mkT.

PALEOMAGNETIC DATING AT THE ATAPUERCA ARCHAEOLOGICAL SITE (BURGOS, SPAIN)

J.M. Parés (Institut de Ciencies de la Terra, CSIC, Sole Sabaris, s/n, 08028-Barcelona, josep.pares@ija.csic.es), A. Pérez-González (Dept. de Geodinamica, UCM, 28040-Madrid), J. Dinarès-Turell (Fort Hoofddijk, Budapestlaan 17, 3584 CD Utrecht, The Netherlands)

A paleomagnetic investigation at the Gran Dolina site excavation has shown that the sediments containing signs of human occupation were deposited well before the Brunhes-Matuyama reversal, yielding evidence for the oldest human occupation in Southern Europe. We have extended our study to the Cueva Mayor karst system and Galeria site excavation and have been able to detect the B-M boundary here also. This enables us to make a stratigraphic correlation between the inner and outer deposits. The lithologies analyzed in this study consist of red-yellow clays, silts, speleothems and bat guano. The horizon that yields hominid fossil remains at Gran Dolina is a massive 15 cm thick red-brownish lutite bed containing dispersed fine clasts. The NRM directions are typically bivectorial, dominated by a distributed spectrum of unblocking temperatures ranging up to 550°C.

THE VARIATION 94+/-5 YEARS 16-13 THOU YEARS BP.

K.S.Burakov,E.Y.Didenko, G.N.Petrova,Z.V.Sharonova (United Institute of Physics of the Earth Russian Academy of Science, B.Gruzinskaja, 10, 123810, Moscow, Russia),
V.G.Bakhmutov (Institute of Geophysics Ukrainian Academy of Sciences)

Investigations of Karelian varves showed that the intensive SV with period T=94+/-5 years existed 12 - 9 thou. years ago. This variation (which isn't present in the observatorium data for the last century) could regarded as a part or a sequel of the Gothenburg excursion.According the results of our investigations the some variations existed 16-13 th.years ago, i.e before the Gothenburg excursion.It can be suggested that appèarance of this variation is connected with low level of geomagnetic moment; during those centuries it was 0.4 - 0.5 from the present one. Fund for this investigation were provided by Soros International Science Foundation grant NFG300.

THE MAGNETIC SUSCEPTIBILITY VARIATIONS OF UZBEKISTAN LOESSES (AGE 53.3 - 22.0 KY B.P.)

Pospelova G.A., Sharonova Z.V. (United Institute of Physics of the Earth RAS, B.Gruzinskaya, 10, 123810 Moscow, Russia)

The collections consist of 1200 samples from 304 levels is studied. The samples were taken from the excavation, have been drilled in the late quaternary loesses Yangiyul section. Two geomagnetic excursions have been discovered and identified with the excursions Kargapolovo and Mono. On the basis of obtained results with an account of geomorphology and partly TL dates it is proposed that the section was accumulated during the time period 31.3 ky. The magnetic susceptibility K variations of rocks in the section change in the limits $250 \cdot 10^{-6}$ - $450 \cdot 10^{-6}$ SI. The oscillations K are stipulated by the magnetic grains concentration. The composition and domain structure of rocks magnetic grains is homogeneous. Anisoptropy K is absent. The spectral analysis by Fourier and MEM methods have been provided. The variation periods of K, determined by the climate variations during the rocks formation, coincide with SV periods of inclination I and declination D. I and D are calculated on the base of paleo-magnetic data of this section. The accuracy of period determination is ±100 years. The maximal amplitude has the period 9300 years. The coincidence of periods K with the periods SV of inclination and declination testifies the relation between geomagnetic and climate changings during the Yangiyul section rocks formation. Probably the sources of their changings are the same and conditioned by the astrophysical factors.

ARCHAEOMAGNETIC INTENSITY IN FINLAND FOR THE PAST 6400 YEARS - PROBLEMS IN TECHNIQUE, DATING ERRORS, OR A NON-DIPOLE FIELD ENHANCEMENT?

L.J. Pesonen and M.A.H. Leino (Laboratory for Palaeomagnetism, Geological Survey of Finland, P.O. Box 96, FIN-02151 Espoo, Finland)

Archaeomagnetic intensity data of Finland for the last 6400 years reveals a peak at AD 500 which is not detected in other regional intensity curves. The peak is not a consequence of the applied version of the Thellier technique, nor due to variations in rock magnetic properties of the materials (grain size, cooling rate, magnetic refraction or fabric anisotropy). A comparison with a new archaeointensity curve for Bulgaria by Daly&LeGoff (1996) may suggests that the Finnish datings at AD 500 are too old by some 120 years: if this correction is made to the Finnish (high latitude) data the agreement with Bulgarian (moderate latitude) archaeointensity curve is fairly good. Relative intensity values of annually laminated lake sediments of Pohjajärvi, Finland (Saarinen, this volume), however, do not show this intensity peak at AD 500. Sediments may, however, miss a very rapid intensity fluctuation due to smoothing processes. If this has taken place, and the datings turn out not to be incorrect, the remaining explanation for the peak is a non-dipole field enhancement. Extrapolation of the present field (IGRF 1990) back in time shows a similar latitude dependent non-dipole field behaviour.

THE BEHAVIOUR OF GEOMAGNETIC FIELD 53.3-22.0 KY AGO ACCORDING PALEOMAGNETIC DATA OF YANGIYUL SECTION (UZBEKISTAN)

Pospelova G.A., Petrova G.N., Sharonova Z.V. (United Institute Physics of the Earth RAS, B.Gruzinskaya, 10, 123810 Moscow, Russia)

The record of two excursions - Kargapolovo and Mono- was discovered in the section of loesses near Tashkent (φ=41°n., λ=69°e.), which was accumulated in time interval 53.3- 22.0 ky B.P. The loop-form "motions" of VGPs were partly arount geographical pole, but mostly around present position of geomagnetic pole. The same tendency of deflexion from geographical axis in longitude sector 180-350° is remarked both during stationary field and during excursions, when VGP reached φ=23°(Kargapolovo) and φ=57°(Mono). The periods of SV of I and D revealed by MEM-analysis for the whole time interval were 700, 1280, 1860, 2590, 3450, 5200, 9800, 24500 years (with accuracy ±100 years). The SV spectrum was not the same at short part of section (before, during and after excursions) , but may be it is artifact provoced by division of I and D rows into short parts.

THE "LOG KRASNY" GEOMAGNETIC EXCURSION IN CROMERIAN, UPPER DON

Pospelova G.A., Sharonova Z.V., Mironov T.V. (United Institute of Physics of the Earth RAS, B.Gruzinskaya, 10, 123810 Moscow, Russia),
Semenov V.V. (Institute of Geography RAS, Staromonetny, 29, 109017 Moskow, Russia),
Levkovskaya G.M. (Institute of the History of Material Culture RAS, Dvortzovaya nab. 18, 191186 S.Peterburg, Russia)

The geomagnetic record of the excursion "Log Krasny" was founded out and studied in subaerial sediments in the basin of the Upper Don in the Lower Pleistocene. The stratigraphic position of geomagnetic record of the excursion is based on two marker beds. The upper marker bed is moraine of the Don glacial lobe, with age about 490 ky by TL method. The lower marker horizon is the reversal M/B. It is established, that the beginning of the excursion took place ~600 ky. The geomagnetic field during the excursion was reversal. VGP was setuated around the south geographical Pole. The field intensity during excursion was 3-4 times decreased in comparison with the intensity of the stationary field near excursion. The "Log Krasny" excursion can be correlated with excursions Elunino VII, Ureki II, Delta. Palynological studies indicated cold climate during the first stage of excursion. Two short-term optimums were at later stage of the excursion. Beginning and termination of excursion were marked by a drastic change of climate. The "Log Krasny" of geomagnetic excursion may serve as an important fact for the stratigraphy of the Cromerian.

HIGH RESOLUTION PALAEOSECULAR VARIATION IN NORTHERN EUROPE DURING THE LAST 3200 YEARS

T. J. Saarinen (Geological Survey of Finland, Betonimiehenkuja 4, FIN-02150 Espoo, Finland)

Variations in the declination, inclination and relative palaeointensity of Earth's magnetic field during the last 3200 years were measured and dated by a study of annually laminated sediments in Lake Pohjajarvi (lat. 62°N), Central Finland. The annual nature of the laminations provides a precise chronology and the pseudo-single-domain (PSD) grain size of the detrital magnetite is ideal for palaeomagnetic studies. The magnetic mineralogy is uniform, with small variations in ferrimagnetic concentration and it was therefore possible to establish a relative palaeointensity record for this high latitude lake. Palaeosecular variations (PSV) were found to be very similar to records reconstructed from other lakes in Finland and North-West Russia. The Late Holocene relative palaeointensity curve can be correlated accurately with archaeomagnetic data from Central Europe, and the PSV curve can be used as an accurate dating tool for other suitable lake sediments.

Paleomagnetic study of the volcanic and sedimentary rocks from Dmanissi region (Georgia). Application to the " European oldest man's " age.

D.Z. Sologachvili, E.SH. Pavlenichvili and A.T. Goguitchaichvili (Tbilissi State University, Geophysics department, Shavtshavadze 3, 380028 Tbilissi, GEORGIA)

In the summer 1991 very important archaeological objects were discovered in the Dmanisi region. ("Patara Dmanissi" archaeological site). A perfectly conserved woman's jaw was found between a thick lava flow and a clay layer deposited above, following another four different clay layers until earth surface. Both geocronological and paleomagnetic study were applied in order to determine the age of the units noted above. The lava flow shows one stable and linear magnetization component , carried probably be low-Ti titanomagnetite. Paleointensity experiments yield relatively small values of the ancient geomagnetic field, about 40% lower than the present day one. Paleomagnetic study from sedimentary rocks was more difficult because of their large magnetic viscosity (viscosity index generally more than 40%). Primary remanent magnetization could not always recognised for those sediments. The obtained data until now allows us to conclude that the paleofield recorded in the studied units may correspond at the end of the Olduvai geomagnetic event. Alternative hypothesis is also proposed.

GEOMAGNETIC INTENSITY IN SOUTHWEST CHINA DURING THE LAST 5000 YEARS

X.G.Huang, Institute of Geophysics, Chinese Academy of Sciences
Q.Y.Wei, Institute of Geophysics, Chinese Academy of Sciences

Geomagnetic field intensity in southwest China (Lat.22° - 32°N, long.100° - 110°E) has been determined for the past 5000 years by using the Thellier method of stepwise thermal demagnetization with about 185 archeological samples (potsherds, bricks, baked clays ets.) from Sichun, Yunnan, Guizhou provinces. Results show a large fluctuation: after slight increase from 57μT to 60μT in the period B.C.3000-B.C.2800, the geomagnetic field intensity decreases rapidly to about 28μT around B.C.2500; hereafter it goes gradually up to 84μT at B.C.1150 following by a sudden decrease to 58μT, a change of "M" shape during B.C.900-A.D.500 with peak value nearly 108μT at about B.C.400 and a sinclike change of small amplitude from A.D.500 till present.

PRELIMINARY ARCHAEOMAGNETIC RESULTS FROM A FLOOR SEQUENCE OF A BREAD KILN IN LÜBECK (GERMANY)

E. Schnepp (NLfB-GGA Hannover, Arbeitsbereich Grubenhagen, Rotenkirchen, 37574 Einbeck, Germany)
R. Pucher (NLfB-GGA Hannover, Stilleweg 2, 30655 Hannover, Germany)

A sequence of 25 bread kiln floors was sampled for archaeomagnetic measurements in a bake-house in the old town of Lübeck, Germany. Due to archaeological dating this kiln floor sequence has been built up presumably from the late 13th up to the 18th century. The primary magnetisation component is carried by magnetite (maghemite) and is very stable. Small viscous magnetisation components could be removed easily. The preliminary results of characteristic remanent magnetisation for 23 of the kiln floor layers show clearly the trend of secular variation which is expected for that time interval. By comparing with the English or British master curves the kiln floor sequence started around 1425 and lasted until 1775 AD. Up to now confidence circles are relatively large and this needs a refinement by measuring more samples, which are already collected. Together with a ^{14}C-age that can be determined on charcoals found in the lowest layers and thermoluminucence dating of the layers we expect to obtain for the first time a secular variation curve lasting about 400 years from one archaeological site in Northern Germany.

ARCHAEOMAGNETIC DATING USING THE INTENSITY OF THE ANCIENT FIELD

Derek Walton (Physics Dept., McMaster University, Hamilton, Ont., L8S 4M1, Canada

Most baked archaeological material, sherds, etc., can only yield the ancient int ensity. In principle this can be used for dating, but in practice has proved imp ossible with the conventional Thellier method. The reason is that the ancient in tensity varies by about 50 per cent, but the error involved in the Thellier method is 30 per ce nt or greater.

Two techniques will be described, and results obtained with them presented, whic h yield reproducibilities of 5 per cent between single samples, which will make dating feasible. The first is a thermal method, and the second employs microwave s to selectivel y heat the magnetic material. Of the two the microwave approach appears to be pr eferable, and it will be discussed in detail.

SE14 Near-surface geophysics: archaeological prospection and archaeomagnetic dating

Conveners: Faßbinder, J.; Hoffmann, V.

03 Near surface geophysics: engineering geophysics

Convener: Papamarinopoulos, S.P.
Co-Convener: Dietrich, M.

THE RESISTIVITY METHOD IN KARST SYSTEMS
Application to Maciço Calcário Estremenho (Portugal)

A. R. Andrade Afonso *. F. A. Monteiro Santos * and L. A. Mendes Victor *
* Faculdade de Ciências da Universidade de Lisboa

The resistivity method was used to detect caves both void and partially or totally saturated with water in the "Maciço Calcário Estremenho".
The pole-dipole and the dipole-dipole arrays were used both in the field work, as well as, in the laboratory.
In the laboratory, the caves were simulated using PVC bodies, with different geometries, which were introduced into the water of an automated resistivity tank analog.
The numerical simulation of the laboratory data was performed considering the caves as empty zones, as well as, bodies whose resistivity was two orders of magnitude greater than the resistivity of the surrounding area.
The results obtained from the tank analog measurements are very well correlated to those calculated by the numerical procedures. So, it seems that we can consider the void zones as continuous areas of high resistivity, and apply the corresponding numerical methodologies. The field data were also well correlated to the calculated ones, in zones of caves whose geometry was known.
All the caves whose existence was known in the survey zone, were detected from the field data processing. Also, "new" caves were detected later on, correlated to high resistivity areas located by the field surveys.

Engineering Geophysical Studies under Complex Conditions of Work of foundation Soils (Grounds) in Western Siberia

W. Bezkhodarnov (United Institute of Geology, Geophysics and Mineralogy SB RAS, Department of Tomsk, 2282, 634055, Tomsk, Russia)

In areas of the river Ob basin and its tributaries, including urban territories, experience of investigation of structure and major properties of friable soils of foundation (grounds) with the help of seismics, electrical prospecting and radioactivity log has been accumulated. Special analysis of seismograms allows one to present a detailed structure of the environment and to receive sections and maps of elastic waves velocities and of different mechanical properties, as well as to calculate factors of dynamic deformations (rigidity). Frequencies of free vibrations of grounds and base-construction sistems are also studied for the latter purpose with the help of a pulsed source. Frequencies of 14-25 Hz, sometimes less than 10 Hz, are typical. About 60 multinomial correlation equations for evaluation of parameters of deformability and strength of soils from geophysical data have been derived for various types of foundations and combinations of static and dynamic effects (loads). Frequently these parameters essentially depend on the depth. The soil inhomogeneity interval according to these properties generally makes 15-60 m (sometimes less than 10 m) in the horisontal and 0.3-3 m (sometimes less than 0.2 m) in the depth. Intervals of horizontal inhomogeneity according to dynamic parameters are 20-30 % less than according to static ones. The unique equipment monitors temporary variations of geophysical fields, as well as vibrations in a range from 2-3 up to 1000 Hz, that permits to use it for detailed evaluation of the base structure (tomography) and for prediction of their behaviour under complex loads.

SUPERVISION OF PHASE INSTABILITY NEAR TO A SURFACE OF A GROUND.

V. V. Chernov, Institute of Applied Physics, Russian Academy of Science, 46 Uljanov str., Nizhny Novgorod, 603600 Russia

Experimental research of a difference of phases between radiated by a signal and signal from the gauge of acceleration, located on a surface of a grou nd, has shown, that during a year the difference of phases changes by a certain image. The conditions of experiment thus remained constant. In experiment were used very stable devices. Supervision have shown, that in some cases the change of a diff erence of phases is caused by change of atmospheric pressure, but in some moment the behaviour of a difference of phases defines the unknown factor: the change of atmospheric pressure occured after c hange of a difference of phases to delay on 1-2 days. Presumably these effects can be explained by influence of gravitational influence of the Mo on and Sun.

THECHNICAL QUALITY CONTROL IN THE JET GROUNTING TREATMENT WITH GROUND PENETRATING RADAR

F. García García, V. Pérez Gracia, J. A. Canas, J. Clapés, R. Osorio, J.O. Caselles and Ll. Pujades. Technical University of Catalonia, Barcelona (Spain).

During the tunnel excavations because of the contruction of one metropolitan subway in a bench-land where the water table was about seven or eight meters depth, a jet-grouting treatment was carried out. The evaluation of the jet-grouting treatment with ground pentrating radar allows to check the continuity and the thickness of this tratment. The radar data show strong reflections in the contact between the alluvial materials and the jet-grouting treatment. It is also possible to observe anomalies in the alluvial soil changed for the injections in constrast with the non-affected ground. With a center 100 MHz frecuency antenna was possible to obtain a good determination of the variations in the thickness of the jet-grouting layer. It was also possible to determinate the layer depth. Three boreholes to determine the quality of the jet-grouting treatment in three check points provide the right calibration of the radar data. Ground penetrating radar allows fast recognition of the treatment layer and a continuous technical quality control. During the processing of the radar data several filters had to be applied to discriminate the radar reflection in the studied layer from the noise produced mainly for the electrical system of the tunnels.

SEISMIC REFLECTION SURVEY FOR ASSESSMENT OF EARTHQUAKE HAZARD AT THE NUCLEAR POWER PLANT SITE (KRŠKO BASIN)

A. Gosar (formerly: Institute of Geology, Geotechnics and Geophysics, Ljubljana; presently: Geophysical Survey of Slovenia, Pot na Golovec 25, Ljubljana, Slovenia)

A seismic reflection profile, 13 km long, was recorded across the Krško basin (SE Slovenia) in the framework of studies for assessment of earthquake hazard at an existing nuclear power plant site. A structural-tectonic setting of this basin, which is filled up by almost 2000 meters of Neogene to Quaternary sediments, was previously not well understood. A folded structure was established that indicates compressional tectonic style. The most prominent reflection horizon corresponds to the Badenian limestone, while the Mesozoic basement is less pronounced. The prevailing hypothesis that the Krško basin is an extensional graben structure with normal border faults was not confirmed. Two subvertical normal faults were interpreted in the central part of the basin. Old analog profiles were reinterpreted too and the interpretation of all profiles was verified by 2D gravity modelling. In addition high-resolution profiling was performed in selected locations for the detection of near-surface (capable) faults. In one profile some anomalous zones were established that can be interpreted as faults, but additional investigations are required. In other profiles there was no evidence of faulting. New structural-tectonic data obtained from the seismic profiling require essential changes of the seismotectonic model on which basis earthquake hazard can be estimated. In reflection investigations engineering seismic equipment was used, while the main part of the data processing was done on a personal computer to reduce costs with respect to conventional recording. In selection of acquisition and processing parameters the emphasis was on enhancement of data resolution and the suppression of source-generated coherent noise.

MATHEMATICAL MODELLING AT ELECTROMETRIC INVESTIGATIONS OF CARST PHENOMENA

E.G.Gritsko (Institute for Applied Problems of Mechanics and Mathematics NASU, 3b Naukova Str., Lviv, 290601, Ukraine) O.Ya.Sapuzhak (Carpathian Branch of Subbotin Institute of Geophysics NASU, 3b Naukova Str., Lviv, 290601, Ukraine)

To study form development and physical characteristics of hollows mathematical modelling methods for near surface electrometric investigations of carst processes followed by certain electroconductivity variations are suggested. The investigations are based on a mathematical model: electroconductive half-space with inclusions of arbitrary form inside it. The boundary element technique is used to solve 3D problem - determining electrical field of current controlled sources in a half-space with in an inhomogeneity. Great attention is paid to mathematical modelling of complex configuration of an inclusion surface. Description algorithm is adaptable and convenient enough for different surface forms to be given. Numerical experiments directed to choosing the ways of accuracy increase of electrical field parameters make it possible to adapt the mathematical model suggested to near surface geophysics needs. Comparative analysis shows that this modelling has real prospects as to more accurate data interpretation of natural electroprospecting observations of carst phenomenon generation and their development. Such methods are noted to be also useful at archaeological searches of objects of high historical signitificance.

2-D WAVEFRONT TRACING IN INHOMOGENEOUS ANISOTROPIC MEDIA.

Michael V. Gurevich , Yuri V. Roslov (Institute of Physics, St.Petersburg University, St.Petersburg, 198904, Russia)

The fast and effective procedure of ray tracing is always of great importance for tomographic purpose. The more close the reference rays to experimental ones are the more accurate the tomographic reconstruction is. Meanwhile the shallow subsurface usually consists of different number of irregular inhomogeneous anisotropic layers where many well known raytracing procedures have weak points. A new high accuracy wavefront tracing traveltime procedure has been proposed by R.L.Coultrip [1] the main advantages of which were the following: (1) uniform-velocity triangular cells is used for the construction of velocity model that allows more accurate approximation of fault planes and dipping beds in compare with rectangular cells. (2) generating wavefield segment method is applied for the approximation of traveltime that also improves the calculation accuracy. Following to R.L.Coultrip procedure we: (1) investigated time-size and space-size approaches for node selection; (2) developed full generating wavefield segment method in more details; (3) extended the theoretical background of the method for anisotropic media; (4) introduced the calculation not only of first but also of second arrivals; (5) compared our results with ones obtained from wavefront tracing method based on rectangular cells. The results show that proposed procedure can be successfully applied for tomographic problems. [1] R..L.Coultrip 1993, High accuracy wavefront tracing traveltime calculation. Geophysics, n.2. vol.58, p.284-292.

SQUARED SEISMOELECTROMAGNETIC RESEARCH OF UNSTATIONARY PROCESSES IN GEOLOGICAL MEDIUM

O.A. Hachay, V.V. Bodin, E.N. Novgorodova (Institute of Geophysics UD RAS, Amundsen Str.100, Ekaterinburg 620016, Russia)

The monitoring results of geological medium show it's unstationarity. The causes of unstationarity displayings are united, so the registration of seismic and electromagnetic fields must be developed in the frame of united squared observation system for the most definition of influence factors in the frame of existing equivalence. The idea of such observation systems construction is supported by the conception on three- staged interpretation of electromagnetic and seismic fields (in the dynamical variant). The developed new squared observation systems are oriented on the use of local exciting sources with united geometrical field structure: electromagnetic field - vertical magnetic dypole, seismic field - vertical exciting with a local strength. The use of artificial local exciting sources allow us to develope an observation system with overlappings. Such observation system together with an original 3-D interpretation complex had been used for solving a series of engenier geological problems, because of their flexibility and simple realisation: by research of dynamics of season and ancient frozen ground zones by frozity and thawity; by volume mapping of discrepancy and filtration zones and research of it's dynamics. That complex showed itself as an informatic and technological device for monitoring of the nature - technogenic processes in geological medium.

A NEW TECHNOLOGY OF MANMADE INFLUENCE UPON PERMAFROST STUDYING

V.A. Istratov, M.G. Lisov, I.V. Chibrikin
121614 Russia, Moscow, st Krilatskie Holmi, G-614, box 44 "Radionda Ltd"

Direct effect upon permafrost which is taking place during man-induced impact may cause hazardous ecological conditions. But it is very difficult to study dangerous geological processes inside permafrost. Application to the problem of the radiowave enlightenment in the interwell area method permits to study and to monitor processes of interaction between permafrost and various fluids such as water, brine and liquid cement injection.

The method is based on multiplying enlightenment of the interwell area by means of high frequency electromagnetic waves during relative movements along wells of dipole transmitter and receiver. Data processing technology takes into account electric anisotropy, diffractive and interferentive effects of local unhomogenities. Sufficient degree of electric contrast of objects been searched for is 1:2 in relation to the host rocks.

Geophysical surveys by means of the method were carried out in the bank zone of Vilui water storage which is being constructed on the permafrost rocks. The reservoirs saturated by brine were revealed inside the permafrost. This reservoirs are fluid conductors and water migration along them from the upper part of the storage is going on. Also there were done 3D quality estimated of cement screen. The screen is being made in the back side of the dam by means of borcholes cement injections in order to prevent landslides and leakage around the jointbetween the river bank and the dam.

SHALLOW SEISMIC INVESTIGATION OF A FAULT ZONE IN URBAN ENVIRONMENTS

Yih Jeng (Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan)
Kuang-Jung Chen (Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan)
Jee-Shiang Wang (Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan)

Shallow seismic reflection surveys were conducted in an area surrounded and traversed by several undetermined faults in the northwestern district of Taipei metropolitan. A cost-effective shear wave generation method was applied to collect the shear wave reflection data. Field-recording parameters were planned according to the restricted space of the urban area. The results of our data processing demonstrate the advantages of employing the synthetic filtering technique to attenuate complex urban noise. Three seismic profiles of reflected and converted waves recorded from the same survey line show different resolutions. Reflection events shown approximately between 650 and 950 ms on the northwest side of the S-wave profile have clearly different reflection character and frequency from those on the southeast side at the same time interval. Diffraction patterns in the S-wave raw data together with the velocity functions of S and P-SV wave data confirmed the structure of a possible fault. The combined interpretation suggests the existence of a possible faulting in the subsurface starting at a depth about 64 m, and our profile probably traverses the southwest extension part of the Gin-San fault.

MODELLING OF THE SCATTERING OF P - SV ELASTIC WAVES BY CRACKED MEDIA

S. Kelner (Laboratoire de Géophysique Interne et Tectonophysique, Université Joseph Fourier, BP 53X, 38041 Grenoble, France)
M. Bouchon and O. Coutant (Laboratoire de Géophysique Interne et Tectonophysique, Université Joseph Fourier, BP 53X, 38041 Grenoble, France)

The problem of scattering of waves by cracks is a subject of interest for geophysicists because it has many applications concerning the Earth's crust: underground storage, oil and gas prospecting, theoretical study of the preparation process of earthquakes, theoretical study of the propagation of waves in heterogeneous media. We have developed a method for computing the elastic wave field diffracted by a series of cracks. The method of calculation used is a boundary integral equation technique in which the Green 's functions are calculated by the discrete wavenumber method. For simplicity, a two-dimensional elastodynamic diffraction problem is considered. The rock matrix is supposed to be elastic, isotropic and homogeneous, the cracks are either all empty or filled with a non viscous fluid, they are assumed to have the same length and strike direction. When the wavelength of the incident wave field is close to, or shorter than the crack length, the scattered waves are efficiently excited and the attenuation of the primary waves can be observed in the synthetic seismograms. On the other hand, when the incident wavelength is greater than the crack length, we can simulate anisotropic properties due to the scattering by the cracks through the time delay of the arrival of the primary wave.

3D ELECTRICAL RESISTIVITY TOMOGRAPHY FOR THE MONITORING OF REMEDIATION PROCESSES

G. Morelli (Laboratory of Advanced Subsurface Imaging, University of Arizona, Tucson (AZ) , U.S.A.)
D. J. LaBrecque (Department of Mining and Geological Engineering, University of Arizona, Tucson (AZ) , U.S.A.), P. Lundegard (Unocal-Cert, Brea (CA), U.S.A.) and A. Ramirez (Lawrence Livermore National Laboratory, Livermore (CA), U.S.A.)

The objective of Electrical Resistivity Tomography (ERT) is to provide images of the subsurface electrical resistivity distribution. Electrical resistivity is a function of the pore water saturation, pore water salinity, soil/rock clay content and temperature. The ERT method uses a combination of numerous surface and borehole electrodes to overcome the limitations in resolution and uniqueness inherent to surface resistivity surveys. Although the ERT method has promise in the characterization of waste sites and the study of shallow geo-hydrology, its greatest strength is the monitoring of changes over time. Thus it has seen increasing use, especially in the United States, in the monitoring of dynamic processes for environmental clean-up. In this work, the changes in interpretation procedures that improve the resolution, reliability and speed of three-dimensional (3D) ERT interpretations will be addressed. To show the effectiveness of the method, presented are applications of 3D ERT to the multitemporal monitoring of environmental remediation processes as Six-phase Electrical Soil Heating, used to extract contaminants from low-permeability soils, and In-situ Air Sparging, used to enhance the removal of volatile organic compounds from permeable soils.

HIGH RESOLUTION GEOELECTRICAL MONITORING OF A SALT WATER INJECTION EXPERIMENT

C. Reissmann (Institut für Geophysik und Geologie, Universität Leipzig, Talstr. 35, D-.04103 Leipzig, Germany, e-mail: georeis@server1.rz.uni-leipzig.dc)

The increase of activities in hydrogeology brings about the intensive application of geophysical methods on the assessment of contamination plumes and ground water migration. The geoelectrical resistivity tomography represents a new quality in aquifer investigation. The injection of salt water into the ground water zone results in the rapid decrease of resistivity within the aquifer. The target of low resistivity, the sodium chloride plume passages through the aquifer. By resistivity monitoring with ground surface arrays the pursuit of the slug is possible. In contrast to other geoelectrical techniques both the statements on the kind of the movement (descent due to density effects, dispersion) and velocity of salt water plume (and hence the ground water itself) and the shape of the slug are to be determinated. These investigations take place within the bounds of a research program which is occupied with the production of ground water derived from river bank infiltration based on Elbe water.

The results of all investigations will be inserted in a program to model flow processes near rivers and wells. Geoelectrical measurements are well integrated in research because geoelectric is a non-destructive method and simple to apply. The salt plume is proved by a rectangular surface array. The measurements are made with dipole-dipole-configuration (dipole length 2m) and Wenner configurations using the multichannel equipment TOMOPLEX by Campus. The data are inverted by a Simultaneous Iterative Reconstruction Techniques SIRT applying the sensitivity theory. By means of the measurements made at several times before and after the injection the three dimensional reconstruction of the salt water plume within the aquifer is very precise.

TO METHODS OF ELECTROMETRIC ENGINEERING INVESTIGATIONS

Ya.S.Sapuzhak, L.M.Zhuravchak, O.Ya.Sapuzhak (Carpathian Branch of Subbotin Institute of Geophysics NASU, 3b Naukova Str., Lviv, 290601, Ukraine)

Engineering-geological investigations are mainly connected with detailed studying near-surface layers which are characteristic of considerable horizontal inhomogeneities. In connection with this methods both of field observations and interpretation of data obtained should be improved. That's why besides traditional method of vertical electrical soundings (VES) profiling by differential sets based on measuring second differences to confine inhomogeneity boundaries is strongly recomended. For VES interpretation mathematical modellig of 2D and 3D inhomogeneities based on an efficientsystem of boundary element techniques and specific fundamental solvings is suggested. The interpretation is carried out by stages. 1) Geoelectric sections are plotted due to the results of 1D interpretation. 2) The results obtained form a basis for 2D modelling by means of which sections are particularized until the data of natural and modelobservations coincide. 3) Plane data available contours of solid inclusions are avaluated according to a profile net similarly to a section their size is elucidated using 3D modelling. Mathematical modelling methods worked out are noted to be useful for determining and choosing optimal as to resolving systems of field observations in specific geological situations at the stage of investigations projected.

INVERSION OF REGIONALIZED Rg WAVEFORMS FOR NEAR SURFACE VELOCITY STRUCTURE IN GRANADA BASIN

M. Navarro, V. Corchete (Departament of Applied Physics, University of Almería, 04120 Almería, Spain)
F. Vidal (Andalusian Institute of Geophysics, University of Granada, P.O.Box 2145, 18080 Granada, Spain)
J. Badal , J. A. Canas (National Geographical Institute, 28003 Madrid, Spain)
L Pujades (Civil Engineering School, Politechnic University of Catalunya, 08034 Barcelona, Spain)

We have investigated the shear velocity shallow crustal structure of the Granada basin (southern Spain) from inversion of fundamental mode regionalized short-period Rg wave group velocity curves. We have used quarry blasts, and were recorded at 8 stations belonging to Andalusian Seismics Network at short distances from the source. In order to perform a regionalization of the region sampled by the paths based on the geology and so distinguish different subregions, we have taken into account the principal geological formations which make up the study area and we have inverted the previous regionalized group velocities by means of the stochastic inverse operator to obtain regional earth models. The inversion results suggest the existence of some degree of lateral variation of shear wave velocity in the region. We observe a good correlation between those changes and the contrasting geology between adjacent geological formations and we display the most conspicuos features of the structure of the region in the upper 3.5 km.

A NEW APPROACH TO A CROSS-WELL TOMOGRAPHY

G.A. Ryzhikov and M.S. Biryulina (Institute of Solid Earth Physics, University of Bergen, N-5007 Bergen, Norway)
K.S.Osypov and J.A.Scales (Department of Geophysics and Center for Wave Phenomena, Colorado School of Mines, Golden, CO 80401, US)

Conventional approachs such as travel-time tomography or full-waveform inversion often fail when applied to cross-well seismic data: the first one because of waveguides, near-field zones and corresponding nongeometrical waves which lead to problems of first arrival picking and interpretation in terms of Fermat's extremals, and the second one because of multipal minima of L_2-norm on waveform residuals. A new approach is suggested which is based on: 1. a proper parametrization of seismic wavefields in terms of so called energetic envelopes; 2. applying of the Kullback-Leibler (KL) measure to fitting of observed and synthetic envelopes. The parametrization of wavefields is tied to an a priori representation of a cross-well space as a medium stratified vertically and perturbed by random transversally oriented inhomogeneities. It allows us to treat every seismic record statistically which in its turn is implied by a time-domain diffusion of energetic wavelets. This procedure provides us with a space-time distributions of energy and makes it much easier to fit the latters with synthetic ones while the main kinematical parameters of unknown medium are fairly saved. A new objective function, that we suggest for dynamic inversion, is the KL-measure, or the relative entropy, on pseudo-probabilistic density functions constructed from energetic envelopes. The approach is illustrated by applying to real cross-well 3C-data with/without additional well log data.

ELECTROMAGNETIC ENGINEERING INVESTIGATIONS IN THE UKRAINIAN PRE-CARPATHIANS

Ya.S.Sapuzhak, V.I.Shamotko, A.I.Bilinskiy, A.L.Petrovskiy, L.M.Mychailjuk (Carpathian Branch of Subbotin Institute of Geophysics NASU, 3b Naukova Str., Lviv, 290601, Ukraine)

Engineering-geological electrometric investigations in the Pre-Carpathian Trough of Ukraine are mainly connected with ecological problems which are due to mining saline and sulphur deposits. The geolgical problems solved were reduced to studying and predicting consequences of sulphate and saline carsts on the territory both of Yavoriv and Kalush integrated mining-chemical works correspondingly and investigating waste repository dam of the latter. For this rational copmlex of plane and regime laboratory and field observations using methods of vertical electrical and electromagnetic impulse and frequency soundings as well as natural impulse electromagnetic field is suggested and tested. The complex locates zones attenuated by carst or filtration processes followed by physical state changes and geoelectrical boundary displacement. Effective materials are vertical sections and maps both of effective and actual values of specific resistivity of layers for spatial observations and relative changes of longitudinal conductivity and averaged value variations of separate electric horizon resistivity or electromagnetic field stress at regime investigation. Natural testing testifies to its efficiency and applicability of the complex for engineering studies and geological section prediction.

DETERMINING THE WEIGHT OF STOCKPILED ORE USING MICROGRAVITY MEASUREMENTS

K.J. Sjostrom and D.K. Butler (USAE Waterways Experiment Station, Vicksburg, MS 39180)

The United States Government maintains stockpiles of high-grade ores at federal installations throughout the country and has requirements to produce current weight estimates as part of annual audits. In computing pile weights, determination of the insitu bulk density of pile material is problematic by any standard geotechnical approach. Thereby, a procedure is developed in which microgravity measurements are acquired over each ore stockpile to provide high-resolution surveys of the gravitational field. Parasnis' method is used to analyze the gravity data to determine the average bulk density of the ore. This method has the advantage of averaging the effect of density variations more accurately than intrusive sampling. Computed weights of each ore pile are compared to the originally reported weights which may be as much as 40 years old.

SEISMOMAGNETISM OF THE FLUID-SATURATED MEDIUM

Yu.P.Skovorodkin (United Institute of Physics of the Earth RAN, B.Gruzinskaya, 10, 123810 Moscow, Russia)
A.N.Kozlov (Institute of the Terrestrial Magnetism and the Radiowave Propagation RAN, 142092 Troitzk, Russia)

The changes of geomagnetic field caused by vibration in the fluid-saturated medium are studed. Vibrations were carried out in the areas of near-surface strata, containing the weekly cemented sandstone. The frequency of vibration changed from 1 to 15 Hz. There were recorded the seismic oscillations and the alternating magnetic field by means of optical-pumped magnetometers. It was found that the maximum amplitude of the electromagnetic signals, caused by seismic wave propagation, were $(11\div14)\times10^{-12}$ T at 1-2 Hz. The amplitude decreased quickly with increasing frequency; the signals attained the noise level at the frequency above 10 Hz.
The observed value of the critical frequency of seismomagnetic signal is a several orders smaller than the theoretical one of seismoelectrical effect. Two mechanisms are considered for interpretation of data. The first mechanism is related with the fluid electroviscosity: the relaxation time of the diffuse part of the double electric layer in a capillar (pore) increases. The second mechanism follows from the violation of laminar current in the real capillars. In the same areas, the "slow" geomagnetic changes were observed, with the amplitude of 1.5×10^{-8} T, during continuous vibration at several hours. These changes had also electrokinetic nature, by arising of additional flow of the fluid filtration, in the vibroactive zone.

USING AZIMUTHAL ELECTROMAGNETIC METHODS TO DETECT LEACHATE PATHWAYS

A. C. Vickery, B. Hobbs and R. Banks (Department of Geology and Geophysics, West Mains Road, Edinburgh. EH9 3JW. United Kingdom.)

This paper considers the problem of detecting contaminant leakage from disused landfill sites. The approach relies on the understanding that so long as all waste materials, in both their solid and liquid forms, are perfectly contained within the bounds of the site then there is no risk of contamination. This assumption eliminates the need for any survey of the landfill itself and highlights the need for a detailed survey of the area immediately surrounding the site. In most cases, only non-invasive geophysical methods are permissible, i.e. subsurface conditions have to be inferred from surface measurements. This paper is concerned with conductive contaminants whose properties and pathways may be evaluated by surface resistivity and/or electromagnetic measurements. Since leachate paths are directional, it is appropriate to consider azimuthal variations in subsurface properties. For a detailed survey of the landfill surround, azimuthal resistivity is time consuming and hence costly. The alternative explored here is the use of azimuthal electromagnetic measurements, which have been compared both theoretically and in the field to corresponding resistivity measurements. The electromagnetic technique seems to offer a useful and cost effective method of leachate evaluation.

DEFORMATIONS IN THE FLUID-SATURATED MEDIUM UNDER VIBRATION

Yu.P.Skovorodkin, T.V.Guseva, L.S.Bezuglaya and A.V.Mishin (United Institute of Physics of the Earth RAN, B.Gruzinskaya, 10, 123810 Moscow, Russia)

The studies of geophysical fields at the vibration of different frequences in some oil- and gas-bearing strata were made. By means of combined high precision measurements during the cycles of vibration, between and after ones, it was found that the temporal changes of fields differed in space. During the vibrations it was observed: 1) in the "neighbouring" zone (< 100 m from the vibrator) - the decrease of the local gravity field (up to 60 mkGal) and magnetic field (up to 5 nT), the horizontal tension (up to 7×10^{-5}) and the uplift (8 mm); 2) in the "distant" zone (hundreds m) - the small increase of the local magnetic field and the change of deformation sign. The recovery of initial level lasts at the period to hours up days, after all vibrations.
This makes possible to develop the model of the deformational processes in fluid-saturated layers on the basis of filtration in the three-phase medium under the influence of the vibrational force. In result of became compact of the collector rocks, during vibration, the additional dynamic pressure arises and causes the filtration along the stratification. While the extracting of fluid from the active zone goes, a consolidation of the solide phase and a separation of the fluid and gas phases take place. Over some time, the equilibrium state eames (it expressed by the stabilisation of geophysical fields). After the end of all vibrations the reverse flow arises, resulting to initial state of the medium.

GRAVIMETRIC MONITORING IN ENGINEERING GEOPHYSICS

Z.M.Slepak (Geological Faculty, Kazan University, 18 Lenin St, Kazan 420008, Russia)

High-precision gravimetric monitoring has bright prospects for the purposes of engineering geophysics. On one of the parts of the Kazan Kremlin's territory (Kazan, Republic of Tatarstan, Russia) that covers 12.000 m² where major architectural memorials,- Suyumbeki Tower and Presidential Palace,- are situated, three cycles of high-precision gravimetric measurements using 5 x 5 m-grid were carried out: in summer and autumn 1995, and in summer 1996. Precision that was possible to reach was as high as 10×10^{-8} m/s². Along with maps and Bouguer anomalies' plots, maps and plots of differential anomalies were drawn. The positive meridional anomaly 10×10^{-8} m/s² was found in the central part of the Kremlin Hill, in the peripheral parts of which there have been found negative meridional anomalies $(-50\ -70)\times10^{-8}$ m/s². Using maps of differential Bouguer anomalies, there have been revealed non-tidal (connected with deep movements of masses) positive and negative gravity changes caused by changes in hydrological conditions. The natural reservoir of rainy and technogenic waters was found to negatively affect the Suyumbeki Tower and Presidential Palace. The centuries-old reservoir could have been a major cause of the Tower's inclination. Considerable decrease in water level of the Kazanka river that washes the Kremlin hill contributed to revealing areas of decreased density which can develop into voids and openings. Recommendations on removal of inclination of the Suyumbeki Tower as well as of possible openings were made.

SITE RESPONSE EVALUATION OF SURFACE SOIL USING MICROTREMOR DATA IN BERJA TOWN (ALMERIA, SPAIN)

F. Vidal, M. Navarro, A. Cheddadi, T. Mourabit, F.J. Sanchez (Andalusian Institute of Geophysics, University of Granada, P.O.Box 2145, 18080 Granada, Spain)
T. Enomoto (Kanagawa University, Faculty of Engineering 3.27.1 Rokkakubashi, Kanagawa-ku, Yokohama 221, Japan)
K. Seo (Tokyo Institute of Technology. Department of Built Environment. 4259 Nagatsuta, Midori-ku, Yokohama 226, Japan)

The soil dynamic properties in Berja town were estimated based on results from the microtremor measurements. Two high-sensitiv seismometers, with a natural period of 1 second, were used to record the horizontal and vertical components of microtremors in each station. The spatial distribution of stations was arranged on the cross points of a grid of 100m x 100m dimensions. Each observation time was of 3 minutes and signals were sampled every 0.01 second. To see the stationarity of the process continuos measurements were made in soft and hard soils during 24 hours (made every hour). The purpose of these measurements were to chek the period and amplitude stability of microtremors in the area.We have obtained de predominant period distribution map and level of amplification, using a version of Nakamura's (1986) method developped by Konno and Ohmachi (1996). The predominant periods of ground motion obtained from H/V ratios were classified in 5 rank intervals: 0.1-0.19, 0.2-0.29, 0.3-0.39, 0.4-0.49 and 0.5 seconds and after that data were plotted to observe space distribution. The dominant periods and the amplification ratio are well correlated with the surface geotechnical conditions and damage distribution.

SHALLOW GEOPHYSICAL INVESTIGATIONS OF KARST GEOHYDROLOGY BENEATH THE YUCATAN PENINSULA AT AKUMAL, QUINTANA ROO, MEXICO

Mike Zimmer, Hans Schwaiger, Craig Murray and Larry Brown (Department of Geological Sciences, Cornell University, Ithaca, NY 14853)
Charles Shaw (Centro Ecologico Akumal, Apartado Postal #127, Playa del Carmen, 77710, Quintana Roo, Mexico)

A series of geophysical surveys, including seismic, ground penetrating radar (GPR) and resistivity, were carried out in 1995/96 in an attempt to detect subsurface cavities and groundwater variations in the coastal karst of the eastern Yucatan Peninsula, Mexico, an area world-famous for its sinkholes (cenotes) and underground rivers. The seismic refraction and reflection data, recorded with a Geometrics Strataview 24 channel seismograph using both 10 and 28 Hz geophones, proved of limited value. Radar profiles and expanding spread data, collected with Pulse Echo IV and 100 systems, were much more promising. Although GPR profiles over several known cave systems were ambiguous, at least one appears to have delineated both a cave roof and an underlying water interface in some detail. In another application, a series of GPR profiles constituting a transect perpendicular to the coast appear to have mapped the top of the halocline. We attribute a rapid and distinctive drop in the radar signal amplitude to the onset of highly conductive salt water, as calibrated against resistivity soundings. We thus suggest that GPR may be a powerful tool for detailed, 3D mapping of halocline "topography", and related subsurface hydrodynamics, when the aquifer matrix (in this case limestone) is sufficiently transparent to radar.

Geophysical control of landslip developments

G.G. Zyatev, V.P. Merkulov, A.A. Nikolsky

The study of landslip processes is carried out by a complex of electrical and seismic methods with registration and processing amplitude, frequency, phase characteristics of signals and their vector representations. The laws of spatial changes of these parameters of signals allow us to allocate in unique way sites of a nonequilibrium stressed-deformed states of mountain massives, forming bodies of landslips. The unique sets of geophysical parameters allow us to diagnose the main deformed horizont as potential or existing base of a sliding zone, areas of compression, stretching and transit of an landslip. The sets of these parameters alter in time, that allows to observe the stages of a preparation of an landslip process and to make on this basis mid- and short-term landslip forecasts. The experience of work in this direction, executed in Tomsk, testifies in favor of an opportunity of a territory differentiation depending on a degree of landslip danger. Subsequent geophysical monitoring gives the basis for engineering and geological investigations to design anti-landslip activities.

SE15 Rock- and palaeomagnetism and environmental magnetism

Convener: Hoffmann, V.

01 Magnetic signature of diagenesis and weathering

Convener: van Velzen, A.J.
Co-Convener: Hirt, A.M.

MICROBIAL REDUCTION OF HYDROCARBONS: CAUSE OF FORMATION OF SECONDARY MAGNETIC MINERALOGIES AT LA VICTORIA OIL FIELD, VENEZUELA

M. Aldana, V. Costanzo-Álvarez, D. Viticllo (Universidad Simón Bolívar, Dpto. de Ciencias de la Tierra, Sartenejas, Edo. Miranda, Venezuela)
M. Díaz, P. Silva (Instituto Venezolano de Investigaciones Científicas, Centro de Física, Altos de Pipe, Edo. Miranda, Venezuela)

Fe-rich spherical aggregates were observed by SEM in drilling fines from oil wells at La Victoria oil field, Southwestern Venezuela. IRM experiments confirm that these aggregates, responsible for the anomalies of the bulk magnetic properties measured at shallow levels in producer wells, are mainly formed by magnetite. The presence of asphaltene, resulting from hydrocarbons biodegradation, was detected by EPR (Electron Paramagnetic Resonance) experiments. The concentration of asphaltene was measured in producer and non-producer wells: greater concentration of asphaltene was found in producer ones. Also, a major concentration was found at those levels were a susceptibility anomaly was measured for producer wells, establishing then a direct relationship between the amount of authigenic magnetite and asphaltene concentration, resulting from hydrocarbon biodegradation. Maps of asphaltene concentration were correlated with micromagnetic and susceptibility maps in this area, in order to further validate these measurements as an alternative low cost tool for hydrocarbon exploration and evaluation.

SECONDARY MAGNETIC MINERALOGIES IN DRILLING FINES OF TWO OIL WELLS (LA VICTORIA FIELD, VENEZUELA): VALIDATION OF AN ALTERNATIVE PROSPECTING TECHNIQUE.

V Costanzo-Alvarez (Universidad Simón Bolívar, Dpto. de Ciencias de la Tierra, Sartenejas, Venezuela)
D Viticllo (BP Venezuela, Edif. Seguros SudAmerica, Ave. Fco. de Miranda, Caracas, Venezuela)

SEM and TEM analyses in drilling fines from oil wells LVT-4X (producer) and LVT-2X (duster) at La Victoria Field (south-western Venezuela), indicate the presence of spherical aggregates of submicronic crystals of authigenic magnetite, only at levels where conspicuous anomalies of bulk magnetic properties have been detected. A causal link between authigenic magnetites and these anomalies is suggested, as well as, a relationship between hydrocarbons and magnetic anomalies above oil fields. At present, we are carrying out a study of secondary magnetic mineralogies and bulk magnetic properties of 15 more wells at this same field. Our final goal is to map the "magnetically anomalous" subsurface, and thus to characterise the underlying reservoir, tracking down possible migration ways of the hydrocarbons towards their present location. Although LVT-2X is a "duster", it lies on the north-eastward migration track of the hydrocarbons, outside the reservoir boundary. The presence of spherical authigenic magnetites and anomalous bulk magnetic properties in this well, could be a fossil documentation of the passage of hydrocarbons through that location in the past.

EVIDENCE OF ORIGINAL SIGNATURE OF THE PALEOFIELD IN SUBMARINE BASALTIC GLASSES

M.T. Juarez (Paleomagnetic Laboratory Fort Hoofddijk, Budapestlaan 17, 3584 CD Utrecht, The Netherlands)
L. Tauxe and J. Gee (Scripps Institution of Oceanography, La Jolla, CA 92093, USA)

Submarine basaltic glasses have SD ad SPM magnetite as the only magnetic mineral within the glassy matrix. Because of this extremely simple magnetic mineralogy, glasses constitute an ideal material for many magnetic experiments in natural samples, but specially for paleointensity studies. Paleointensity experiments on Cretaceous and Holocene ODP glasses have indeed given reliable results (Pick and Tauxe, 1993, 1994). For that reason we have carried out new paleointensity measurements on Eocene (ODP sites 513A, 522B, 447A), Oligocene (ODP sites 238, 559, 563, 564, 558) and Miocene (ODP sites 520, 562,472, 470A, 504B, 396B) submarine basaltic glasses. As it is well known paleointensity experiments will give rise to incorrect results if alteration of the original magnetite occurs during its geological history. In order to check the reliability of our results we have carried out several rock magnetic experiments (experiments at low-temperature, Curie balance and agfm measurements, etc.) in glasses from Cretaceous to Holocene ages. We have been looking for long- or short-term alteration in the glasses. Our results show that a relationship can be established between the Fe content in the glass and some of the magnetic parameters, while no connection could be detected between any of those parameters and the age of the glasses. These results suggest that paleointensity differences between the different age glasses probably reflect variations in the actual paleofield strength.

CRM and Burial Diagenesis of Smectite

B. Katz (School of Geology and Geophysics, Norman, Oklahoma 73019, USA)
R.D. Elmore, M. Cogoini (School of Geology and Geophysics, Norman, Oklahoma 73019, USA) & S. Ferry (Universite de Lyon, Villeurbanne, France)

Paleomagnetic and rock magnetic results from Jurassic/Cretaceous carbonates in the Vocontian Trough (SE-France) indicate an association between burial diagenesis of clays (smectite alteration) and the type of magnetization encountered. A primary magnetization was identified only at one location where little diagenetic alteration of the clay minerals occured. A pervasive magnetization is present in units in which smectite has altered completely. This magnetization is prefolding and secondary based on fold tests, a conglomerate test, a "slump-test", and reversal tests. Studies of the magnetic mineralogy indicate that magnetite carries the magnetization which is interpreted to be a chemical remanent magnetization (CRM). In younger units with abundant smectite, the CRM is either unstable or poorly defined. These results are consistent with the creation of a magnetization during burial diagenesis of smectite. Preliminary rock magnetic results suggest some differences between rocks from the different clay diagenetic zones, although there do not appear to be significant variations in the hysteresis properties.

STRESS METAMORPHISM EFFECT ON THE NATURAL REMANENT MAGNETIZATION OF ROCKS

D. V. Mitrokhin, A.Yu. Kazansky (United Institute of Geology, Geophisics & Mineralogy, Siberian Branch of Russsian Academy of Sciences, Universitetsky ave., 3, Novosibirsk, 630090, Russia).

Paleomagnetic results have been obtained from the Lower Cambrian sections of the North Sayan Zone, West Sayan (Russia). This study was carry out in order to research the affect of stress-metamorphism onto the NRM of deformed rocks. It was found that the rocks experienced superimposed stress metamorphism are able to attain the magnetization which orientation coincides with the direction of shear deformation and with the orientation of deformed structures. Moreover, stress metamorphism may completely remove the primary magnetization of rocks which in turn may carry the information about the secondary deformation magnetization. The role of stress metamorphism processes apparently is not restricted by a simple rotation of elongated grains of magnetic minerals along the direction of shear deformation: there are samples in which the rotation of grains is not clearly observed, however, the ChRM vector is already oriented parallel to deformation structures (cleavage). Those conclusions are confirmed by new paleomagnetic results from Middle Carboniferous sequence of Northern Part of Zaysan Depression (Kazakhstan).

Diagenetic alteration of the magnetic signal in marine sediments : Discrimination of the contributions to the NRM

M. Urbat and M.J. Dekkers, Utrecht University, Faculty of Earth Sciences, Paleomagnetic Laboratory Fort Hoofddijk, Budapestlaan 17, 3584 CD Utrecht, NL

Changes in rockmagnetic parameters indicate considerable diagenetic modifications of the magnetic signal in Pleistocene passive margin sediments off New Jersey (ODP Sites 903, 904) as a function of depositional hiatuses. The primary detrital NRM is partly overprinted due to diagenesis. A similar rockmagnetic study shows that the ferrimagnetic signal in hemipelagic sediments from the Japan Sea (ODP Hole 798B) has been entirely altered by diagenesis. The rockmagnetic patterns can be related to local environmental changes. The original detrital input, however, can still be traced in the paramagnetic part of the signal which can be correlated to the SPECMAP oxygen isotope curve. Hence, environmental magnetic methods can be applied to situations where the NRM acquisition mechanism is complex. When interpreting data, it seems more appropriate to focus on (even small) relative changes between rock magnetic properties rather than to determine absolute magnetomineralogical grain sizes or concentrations alone. We are presently integrating multivariate statistical methods (factor analysis, (fuzzy) cluster analysis and non-linear mapping) to facilitate and extend the interpretational procedure. The long-term goal is to develop a rockmagnetic interpretational frame which is less dependant on geochemical and sedimentological information.

POST-DEPOSITIONAL REMANENT MAGNETISATION AND ITS IMPORTANCE FOR PALAEOMAGNETISM

V.V.Kochegura (All-Russian Research Geological Institute, 199026 Sredny pr. 74,St.Petersburg, Russia)
S.A.Pisarevsky (All-Russian Petroleum Scientific Research Geological Exploration Institute, Liteiny 39, 191104 St.Petersburg,Russia)

The results of experiments carried out for study and modelling of the post-depositional remanent magnetisation (PDRM) of the sea-floor and lake sediments, loesses and volcanic ashes are presented. It is clear from these experiments that the intensity of the post-depositional magnetisation ranges in wide limits and sometimes exceeds the primary (detrital) remanent magnetisation (DRM) up to four times. The remanent magnetisation of volcanic ashes is usually built up during several tens of years mainly by dynamic influence of the penetrating atmospheric moisture, and the primary DRM is practically absent in these sediments. The experiments with loesses and lake sediments confirmed the significance of the moisture in the creation of the PDRM. The obtained data show that PDRM reflects a direction of the geomagnetic field for hundreds and more years after deposition. Combined with the primary DRM this secondary PDRM disturbes the palaeomagnetic record in the sedimentary sections. It causes many difficulties for the study of the fine structure of the palaeomagnetic field - palaeosecular variation, excursions, events and geomagnetic reversals.
The laboratory PDRM created in the samples when kept in natural moisture conditions was also studied. Some means for reducing of the influence of PDRM on the palaeomagnetic reconstructions were obtained

THE ORIGIN OF FERRIC HYDROXIDES IN SEDIMENTS OF EAST-EUROPEAN CONTINENT SHELF ACCORDING TO PALEOMAGNETIC DATA

I.A.Svyazhina, R.A.Kopteva, Z.S.Mezenina (Institute of Geophysics of the Urals branch Russian Academy, Amundsenstr. 100, Ekaterinburg, 620016, Russia)

In the Southern Urals Ordovician deposits of East-European continent shelf were studied. Paleomagnetism of sandstones depends on goethite and only partially - on hematite. The first is bound with late-Paleozoic component of magnetization $D=232^0$, $I=-29^0$, the second - with early-Paleozoic component $D=328^0$, $I=26^0$. Ferric hydrooxides were diagnosed by magnetic methods. Sandstones are of weak magnetization. During thermomagnetic analysis a sharp drop of J_n and J_{rs} in the interval between 280^0 - 350^0 C was fixed. On repeated curres this step was absent. Magnetic parameters of saturation changed with heating: at 600^0 C the J_n value increased 10-36 times and H_{crs} - slightly decreased. Under the affect of temperature sandstones acquired red and brown colouring of different intensity. The colour changed along cracks and spots and finished at 280^0 C. The process of secondary colouring might be separated from the time of sandstones' formation. The emergence of goethite is bound with late-Paleozoic laterite weathering. By that time Ordovician sandstones were exposed due to erosion and peneplanation of a folded area, and the continent itself was situated in low tropical latitudes

LOW-TEMPERATURE OXIDATION OF MAGNETITE IN NATURAL ROCKS

A. J. van Velzen (Department of Earth Sciences, Oxford University, Parks Road, Oxford, OX6 3PR, UK)

In the initial stages of low-temperature oxidation of magnetite coercivities increase due to differential oxidation in magnetite grains. The more oxidized shell shrinks and is stretched over the less oxidized core. In larger grains this will cause cracks. The effect occurs at low temperatures, because then the oxidation gradient is high. Heating the magnetite to 100 C may lead to a reduction of stress and consequently a decrease of coercivities. The increase of coercivities has been observed after low-temperature oxidation of ocean floor basalts and after weathering of Pliocene marine sediments. Low-temperature oxidation might occur in many other rock types. For paleomagnetic purposes this may have little effect as long as thermal demagnetisation is used. Initially the oxidation only stabilises the remanence. Alternating field demagnetisation will be inadequate, however. Coercivities might be misinterpreted, because they can reach values that are anomalously high for magnetite (up to 0.5 T). A collection of different magnetite bearing rocks is tested for the effect of low-temperature oxidation.

THE NEOGENE REMAGNETIZATION IN WESTERN BETICS (SOUTHERN SPAIN). THE HYPOTHESIS OF A THERMOVISCOUS REMANENCE.

J.J. Villalaín (Dpto. Física Aplicada, Escuela Politécnica, Universidad de Burgos, Avda. G. Vigón S/N, 09006-Burgos, Spain)
M.L. Osete (Dpto. Física de la Tierra I, Fac. Ciencias Físicas, Univ. Complutense, 28040-Madrid, Spain)

Palaeomagnetic investigations in Upper Jurassic carbonate rocks from Western Subbetics (Betic Cordillera, southern Spain) demonstrate the existence of a widespread Neogene remagnetization. The NRM is dominated by a pervasive Neogene overprint, which always shows normal polarity and maximum unblocking temperatures of 450°C throughout the whole studied region. The incremental fold test performed in all sampling localities indicates that the remagnetization occurred during some stage of the Neogene deformation of the Subbetics, being pre, syn- or post-folding in the various folds studied. The hypothesis of a thermoviscous remagnetization to explain this phenomenon is investigated. Experiments on viscous and thermoviscous magnetization have been carried out to determinate the adequate thermal activation of magnetization theory. This theory estimates palaeotemperature values of about 250°C for the Jurassic limestones of the western Subbetics.

SE15 Rock- and palaeomagnetism and environmental magnetism

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02 Environmental magnetism with emphasis on calibration of magnetic methodology

Convener: Heller, F.
Co-Conveners: Oldfield, F.; Snowball, I.F.

THE MINERAL TRANSFORMATIONS IN CRYOGENIC SOILS

A.O.Alekseev, T.V. Alekseeva, V.E.Ostroumov (Institute of Soils Science & Photosynthesis of RAS, Pushchino, Moscow region, RUSSIA),
C.Siegert (Alfred Wegener Institute of Polar and Marine Research, Potsdam Research Department, GERMANY)

The effect of the processes of seasonally freezing - thawing on the mineralogical transformations in cryogenic soils (Kolyma lowland, Russia) has been investigated by magnetic measurements, Mössbauer spectroscopy and XRD. High $Fe^{2+}/(Fe^{2+} + Fe^{3+})$ ratio - 30-40% (up to 50 %, in freeze loamy sediments) reflects the low intensity of weathering processes. Fe^{2+} occupies the structural positions in glauconite, palygorskite , hydromica, chlorite. Goehtite, hematite and other oxides have not been observed by means of Mössbauer spectroscopy. The results of thermomagnetic analysis demonstrate the presence of lepidocrocite. As result of the seasonally dynamics (temperature, moisture, pH, Eh, etc.) the decreasing of Fe^{2+} content, increasing of Fe bulk in clay fraction (twice) and the highest concentration of lepidocrocite in zones with the maximum freezing-thawing take place. The magnetic susceptibility in permafrost soil-ground complex reflects the processes of distribution of Fe compounds at the Frozen Geochemical Barrier.
This research is financed by INTAS-93-0266 grant.

MAGNETIC SUSCEPTIBILITY AND HYSTERESIS LOOP PROPERTIES OF LATE QUATERNARY LOESS-PALEOSOL DEPOSITS OF HARO RIVER AREA, ATTOCK, NORTHERN PAKISTAN

Huma Akram, Mirza Naseer Ahmad and Mitsuo Yoshida (Geoscience Laboratory, Geological Survey of Pakistan, Shahzad Town, Islamabad.)

Rock magnetic properties of Late Quaternary loess-Paleosol deposits for 38 samples collected from four different sites of Haro river area in Pakistan were studied. Chemical data is similar to Kashmir and Chinese Loess. Magnetic methods such as IRM acquisition experiment and thermomagnetic analysis indicated the presence of magnetite, accompanied by trace amounts of maghemite and goethite. Hysteresis loop parameters show that most of the magnetic grains are of MD in nature and some of them are of PSD. The hysteresis loop parameters such as coercive force and ratio of remanent magnetisation to saturation magnetisation increase with the increase of finer fraction (< ϕ 0.3μm) of the clay percentage, which proves that magnetic methods can be used for grain size differentiation in these loess deposits. The SIRM values shows that the concentration of magnetic minerals is not high in paleosols as compared to the loess therefore magnetic susceptibility is also not high in the case of paleosols as compared to the other loess beds, which shows a very different behaviour from typical loess-paleosol sequences in the Chinese Loess Plateau. ARM was normalised by SIRM showing that this ratio was comparatively high in the paleosols than in loess which is indicating the presence of pedogenic ultra fine magnetite/maghemite grains.

PALEOCLIMATIC RECORD FROM THE MAGNETIC SIGNATURE OF MARINE AND LACUSTRINE SEDIMENTS IN CENTRAL ITALY

F Alvisi and L. Vigliotti (Istituto di Geologia Marina, CNR, Via P. Gobetti 101, 40129 Bologna, Italy)

This study presents some results obtained in the framework of an EU Project (PALICLAS) aimed at reconstructing the paleoclimatic changes during the past 25 kyr in central Italy. Natural and laboratory-imparted rock magnetic properties have been measured from marine and lacustrine cores of Late Pleistocene-Holocene age collected in the Adriatic Sea and in the crater lakes of Albano and Nemi. Rock magnetic parameters provide a significant correlations with the climatic reconstruction based on different proxies record such as pollen analysis and planktonic foraminifera assemblages. The magnetic mineralogy of the Adriatic cores is dominated by magnetite whereas minerals with higher coercivity (hematite-type) characterize intervals with low magnetic content in the lacustrine cores. Concentration-dependent parameters (K, ARM, SIRM) and interparametric ratios (K_{ARM}/K, SIRM/K, SIRM/ARM) allow us to discriminate the late glacial deposits of the marine cores with respect to the Holocenic sediments. The latter exhibit a lower magnetic content and a finer grain size that reflect a landward shift of the source area of the terrigenous imput during Holocene time. Intervals of different magnetic content, related to changes in the depositional environments, characterize the Albano and Nemi cores. These changes indicate fluctuations in the lake level that can be associated to climatic variations. The coincidence of magnetic subzone with significant pollen assemblage in the Nemi core supports the influence of the antropic impact on the lake catchment.

MAGNETIC CHARACTERISATION AND QUANTIFICATION OF SEDIMENT EROSION IN THREE LAKE CATCHMENTS IN THE HUMBER REGION, NORTHERN ENGLAND.

D. Barlow, R. Thompson (Geology and Geophysics, University of Edinburgh, Edinburgh, United Kingdom)

Lake sediment cores have been collected from three sites in the Humber region, northern England. Exceptionally high levels of sediment accumulation are found at each site. Sediment has been characterised using a variety of techniques including mineral magnetism, X-ray diffraction and particle size analyses. Cores obtained from Hornsea Mere have been correlated succesfully using variations in mineral magnetic signature. A correlation between changes in particle size and magnetic characteristics in a core from Raydale has been obtained, regression analysis shows that sediment less that 1 μm accounts for over 50% of the variation in magnetic signature. This result has been confirmed by magnetic measurements undertaken on individual particle size splits.

A particularly extensive Holocene lacustrine valley fill containing an estimated 10 million cubic metres of sediment has been identified at Raydale in the Pennines. This translates into a mean catchment delivery rate of 48 kg ha^{-1} a^{-1} throughout the Holocene. At Gormire in the Hambleton Hills a delivery rate of 80 kg ha^{-1} a^{-1} has been calculated. At Hornsea the magnetic minerals appear to be dominated by bacterial magnetosomes.

MAGNETIC PROPERTIES OF PLIO-PLEISTOCENE SOILS FROM THREE SYSTEMS OF RIVER TERRACES IN CENTRAL SPAIN AND THEIR PALEOCLIMATIC IMPLICATIONS

M.F. Bógalo, M.L. Osete and P. Keller (Dpto. de Geofísica, Universidad Complutense, 28040 Madrid, Spain)
A. Pérez-González (Dpto. de Geodinámica, Universidad Complutense, 28040 Madrid, Spain)
J. Gallardo (Dpto. de Edafología, Universidad Politécnica. 28040 Madrid, Spain)
F. Heller (ETH-Zurich, CH-8093, Zurich, Switzerland)

In order to investigate the evolution of magnetic properties and environmental changes with age from Plio-Pleistocene to Holocene in Central Spain, soil profiles from three different systems of river terraces (Tajo, Jarama and Arlanzon) have been studied. The river systems are developed on the Spanish Meseta with differences amongst them in annual temperature and rainfall. Systematic study of magnetic properties was carried out: Frequency dependent susceptibility (χ), susceptibility as a function of temperature, hysteresis parameters (H_c, H_{cr}, J_s, J_{rs}), anhysteretic remanent magnetisation and natural remanent magnetisation. In most of the studied soils, χ and J_{rs} show a similar behaviour with depth: an enhanced surface horizon (A and the upper part of B) and a stable B and C horizon. The magnetic parameters depend similarly upon age for the three different systems of terraces. The enhancement of χ increases with age from Holocene to Late/Middle Pleistocene, decreases on the Middle/Early Pleistocene terraces, and again increases during Early Pleistocene. This pattern of magnetic properties suggests a paleoenvironmental change in Central Spain during the Middle Pleistocene.

PALAEOENVIRONMENTAL CHANGES DOCUMENTED BY MAGNETIC AND PALYNOLOGICAL METHODS IN LOESS SEDIMENTS OF THE UPPER DON REGION (STRELITSA TYPE SECTION)

N.S. Bolikhovskaya, S.S. Faustov, E.I. Virina (Moscow State University, Geography Department, Vorobyevy Gory, 119899 Moscow, Russia)
R.V. Krasnenkov ("Geosintez" Varshavskoe shosse 39a, 113105 Moscow, Russia)
T.S. Gendler (UIPE, B. Gruzinskaja 10, 123810 Moscow, Russia)
F. Heller (ETH Zürich, CH-8093 Zürich, Switzerland)
J. Hus (Centre de Physique du Globe, B-5670 Dourbes, Belgium)
E.A. Hailwood (Southampton University, Southampton SO9 5NH, UK)

A full loess-palaeosol series with six palaeosols overlying the Don moraine (Upper Cromerian) was studied by magnetic and palynological methods. Major climatic changes are recorded in the susceptibility profiles. Maxima correspond to interglacial and minima to glacial conditions whereas minor climatic changes often do not show up in the magnetic record. Smoothing and delay of the magnetic signal may be explained by the slow magnetic climate-related response of the sediments. Connection of magnetic properties with palaeosol composition is very clear: high magnetic intensities are observed in dark humified horizons, low signals in loesses and little humified transitional and/or gleyed and leached palaeosol horizons. Magnetic enhancement is connected mainly with the humus content. Magnetic minerals are represented by "soft" (magnetite or maghemite) and "hard" (haematite) phases. The first ones are mainly responsible for the magnetic climate signal. Analysis of the temperature dependence of saturation isothermal remanent magnetization revealed different behaviour for deposits formed during cold and warm conditions.

MAGNETIC CHARACTERISTICS OF BULGARIAN LOESSES AND PALAEOSOLS

V.A. Bol'shakov (Geographical Faculty of the Moscow State University, Moscow, 119899, Russia)

This work is based on study of magnetic properties of three loess-soil outcrops in the Nothern Bulgaria. Up to six horizons of palaeosols (PS) and loesses (L) are established in these outcrops. According to palaeomagnetic and rock magnetic data the lowermost horizons of PS and L were formed rather during Late Pliocene than Pleistocene. Magnetic susceptibility c, thermomagnetic characteristics, magnetic viscousity, hysteresis and parameters of domain state of L and PS were measured. The obtained data confirm the previously established correlation between magnetic properties of PS and L. 1.The automorphous soils are more magnetic than loesses. Maximum c value in soils is 8 times higher than minimum c value in loesses. 2.The size of PS magnetic particles is smaller than that of L ones. First of all it is confirmed by the values of parameter Ii/Is, where Ii is anhysteretic remanence, Is - saturation magnetisation. Besides this, the investigation of Bulgarian outcrops leads to the conclusion that the newly formed fine magnetic mineral of automorphous palaeosols is characterised by: 1)the temperature Curie~520 C, 2)the absence of minimum dIrs/dT (180-200) C (as compared to loesses), where Irs is saturation remanence, T - temperature. One of the possible explanation of our data is that such properties may be connected with the substituted magnetite. In this case magnetite can not be of biogenic origin, according to the works of Fassbinder et al. and Moskowitz et al.

CONNECTION OF MAGNETIC PROPERTIES OF THE WESTERN BLACK SEA SEDIMENTS WITH ENVIRONMENTAL CONDITIONS IN LATE PLEISTOCENE AND HOLOCENE

V.A. Bol'shakov S.D. Nikolaev (Geographical Faculty of the Moscow State University, Moscow, 119899, Russia)

Magnetic and palaeomagnetic investigations of the western part of the Black Sea bottom sediments were perfomed. Magnetic susceptibility of the shallow sea cores (obtained from the depth less than 88m) is small and monotonously distributed along the core. Distribution of magnetic susceptibility and Koenigsberger ratio for deep sea cores (obtained from the depth more than 162m) has several maxima. The first extension of magnetic susceptibility value occure in the upper part of the marking hydrotroilitic horizon of NeoEuksinian sediments. The second general peak of magnetic susceptibility was found at the base of Kalamitian sediments. In the lower parts of cores distribution of magnetic susceptibility is more monotonous. Magnetic properties of this sediments are connected with magnetite, maghemite and haematite. Pyrite and magnetic minerals with Curie temperatures ranging from 180 C to 350 C (most of all pyrrotite and greigite) were found in the upper core layers begining from the hydrotroilitic level. Palaeomagnetic excursion Goetenburg was recorded right under the marking hydrotroilitic level. We connect variations of magnetic properties with an influx of the Mediterranean Sea salt water into the Black Sea basin about 12 thousand years ago. This influx resulted in development of sulphat reduction processes and ferrum sulphides formation.

NATURE OF ANOMALOUNS MAGNETISATION IN THE LOESS-SOIL HORIZON OF "VETOVO" OUTCROP (BULGARIA)

V.A. Bol'shakov (Geographical Faculty of the Moscow State University, Moscow, 119899, Russia)

Magnetisation anomaly was found in the fifth from the top loess horizon (L5) during palaeomagnetic investigation of "Vetovo" outcrop. Direction of magnetisation is nearly horisontal (inclination I>3 , declination D>240). Koenigsberger's ratio of specimens ranges from 14 to 20. Comparative magnetic investigation of the loess L5 and other loess horizons was carried out. Changes of saturation magnetisation (Is), saturation remanence (Irs), natural remanence magnetisation (In) under influences of temperature (T) and alternative magnetic field (h) were studied. Irs(T), Is(T) - curves are similar but In(T), In(h) are different for the specimens of loess L5 and other loess horisons. Additional sampling was made from the main section and the other sites along the L5 horizon. Direction of anomalous magnetisation in the main section practically does not change within more than 0.6m of the section. Anomaly covers the lower part of loess L5 and the upper part of the underlying fossil soil specimens collected in other sites of L5 layer have close to horizontal magnetisation directions, but their declinations differ considerably from declination in the main section and from site to site also. The analysis of the obtained data leads to the conclusion that anomalous magnetisation is connected with a striking. The most effective mean of identification such magnetisation in continental sediments is specimen sampling along anomalously magnetized stratum.

ROCK MAGNETISM AS A PALEOCLIMATE PROXY IN THE LOESS SEQUENCE AT NUSSLOCH, GERMANY.

E. Cocuaud, D. D. Rousseau, (Université Montpellier II, Paléoenvironnements & Palynologie, UMRS CNRS 5554-Inst. Sci. Evolution, case 61, pl. Bataillon 34095 Montpellier cedex 05 France).
P. Antoine (Université des Sciences et Technologies de Lille, Laboratoire de Géomorphologie et d'Etudes du Quaternaire, 59655 Villeneuve D'Ascq cedex France).
C. Hatté, M. Fontugne (Centre des Faibles Radioactivités, domaine du CNRS, avenue de la Terrasse, 91 Gif-sur-Yvette, France).
L. Zöller (Forschungsstelle Archäometrie der Heidelberger Akademie der Wissenschaften am Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg Germany).

Parallel investigations of rock magnetism, sedimentology, organic carbon content, and TL measurements allow to characterize the variations of the last climatic cycle in the Rhine valley. These oscillations are in agreement with more general climatic changes as observed in the GRIP record.

MAGNETIC PROPERTIES OF DUANJIAPO LOESS SECTION, LANTIAN COUNTY, SHAAXI PROVINCE, CHINA

F. Florindo (Istituto Nazionale di Geofisica, Rome, Italy)
R. Zhu, Y. Pan and B. Guo (Institute of Geophysics, Chinese Academy of Sciences, Beijing, China)
L. Yue (Department of Geology, Northwest University, Xian, China)

The typical loess stratigraphy in China consists of an alternating loess and palaeosol layers. The loess represents dust deposition under cold semi-arid climatic conditions while palaeosols are developed from loess in a warm humid environment by weathering. The Duanjiapo loess section (34.2° N, 109.2° E) is located in the southern part of the loess plateau, at about 30km southeast of the city of Xian. It consists of a sequence of 33 loess-paleosol strata with a total thickness of about 132m. It overlies the Red clays Formation, which is about 40m thick. 150 bag samples were taken at 5cm intervals from the loess and paleosols succession L0-S0-L1-S1-L2, including the last two glacial cycles (corresponding to marine $\delta^{18}O$ stages 1-6). The results of detailed rock magnetic characteristics of these samples from the uppermost 7.5m of the section are reported and compared with those from Weinan loess section (34.4° N, 109.5° E) which is very near the Duanjipo loess section and contrasted with westerns sites.

ROCK MAGNETIC, PEDOLOGICAL AND MOESSBAUER STUDY OF CLAY FRACTIONS FROM THE LOESS-PALAEOSOL SEQUENCE AT ROXOLANY (UKRAINE): POSSIBLE ORIGIN OF THE MAGNETIC SIGNAL IN THE PALAEOSOLS

T.S. Gendler, V.I. Bagin , E. Haliulina (UIPE, B. Gruzinskaja 10, 123810 Moscow, Russia)
E. Virina (Moscow State University, 119899 Moscow, Russia)
F. Heller (ETH Zürich, CH-8093 Zürich, Switzerland)
J. Hus (Centre de Physique du Globe, B-5670 Dourbes, Belgium)
E.A. Hailwood (Southampton University, Southampton SO9 5NH, UK)
A. Tsatskin (University of Haifa, Haifa 31905, Israel)

Rock magnetic, palaeopedological and Mössbauer characteristics of loess-palaeosol sediments from Roxolany were studied using both bulk samples and clay fractions in order to investigate the origin of magnetic low field susceptibility (χ). Clay fractions were separated from most of the pedocomplexes (PK). The study included comparison of χ, saturation (M_s) and isothermal remanent (IRM) magnetization and their temperature dependence, Mössbauer spectra (S) at 300K and 80K for both bulk and clay samples. M_s, IRM, S and superparamagnetic Fe-oxides/hydroxides increase in the clay fractions ca. 1.5-4 times. The variations inside each PK are similar to those of χ: they reach maximum values in the A, AB soil horizons but are minimal in the B_{ca} horizons. The main palaeosol Fe-minerals are ferruginous smectites. It is suggested that the soil ferromagnetic minerals originate as a result of the ability of indigenous soil microorganisms to reduce structural Fe in swelling clay minerals. The formation of free Fe-oxides as fine dispersed and superparamagnetic magnetite may be a consequence of the reducing bacterial activity in soil environments.

MAGNETIC SUSCEPTIBILITY AND HEAVY METALS IN SOILS FROM MALÉ KARPATY MTS. (SLOVAKIA)

O. Ďurža and S.Y. Mejeed (Department of Geochemistry, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovakia)

The purpose of this study is to assess the heavy metals contamination in soils of the SW part of Malé Karpaty Mts. utilizing soil kappametry. Since the aim was not to find the efect of substrata (geological) on soil magnetic susceptibility (χ) but the effect of topsoil contamination (anthropogenic), the relative topsoil enhancement (RTE) of elemental concentrations and values of magnetic susceptibility was determined. RTE is the ratio of element concentration in topsoil (0-15 cm) to that in subsoil (30-45 cm) as an index of surface contamination (Colbourn and Thornton 1978) and coresponds to the relative topsoil enhancement of magnetic susceptibility values. It was found by cluster analysis that the determined RTE of elements are divided into three groups by their relation with RTE of χ: the relatively strongest relation - Pb and Hg; relatively weaker relation - As, Cu, Sb, Zn, less Mn, Ni and Cd; the relatively weakest relation - Co and Fe. The highest values of RTE of χ and RTE of elemental contents occur in NW slopes of Malé Karpaty Mts. and in the profile near Bratislava. The contents of Hg, Pb and their sum show the relatively strongest relation with χ (+0.55, +0.51, +0.61 respectively). It is probable that one of the sources of soil pollution is the influence of the town Bratislava. The higher contamination of NW slopes is probably due to several more distant sources under the influence of prevailing NW winds.

ADVANTAGES OF A MULTI PARAMETER APPROACH FOR THE INTERPRETATION OF MAGNETIC RECORDS FROM SMALL LAKES

Ch.E. Geiss, S.K. Banerjee (Institute for Rock Magnetism, Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, USA)

Small lakes can be good recorders of local paleoclimate variations, and rock magnetic measurements have been shown to be a valuable complement to classic paleoclimatic parameters, such as pollen assemblages or isotope data. However, the processes that affect the sedimentological and rock magnetic properties of small lakes can change dramatically. Since different environmental processes can result in quite similar rock magnetic properties of the sediments, a simple model that is based only on a few magnetic parameters might lead to serious misinterpretation of the magnetic record. We studied cores from Pittsburg Basin, a small kettle lake in southern Illinois, whose sedimentary record spans the Sangamon interglacial and goes back into late Illinoian glacial sediments. X-ray diffraction analysis and Curie temperature measurements indicate that the main magnetic carrier throughout the core is partially oxidized magnetite. Grain size dependent magnetic parameters , such as anhysteretic remanent magnetization (ARM) normalized by saturation isothermal remanent magnetization (SIRM), show an apparent correlation with the marine oxygen isotope record where fine grained magnetic fractions correspond to the warm substages of marine isotope stage 5. Susceptibility variations, on the other hand, suggest multiple hydrological events that defy a consistent interpretation. We show that cooling through the Verwey transition in the presence or absence of a 2.5 T field, temperature and frequency dependence of susceptibility, and lithologic variations, taken together, lead to a more accurate, self consistent interpretation.

PALEOPEDOLOGICAL AND BOTANICAL CALIBRATION OF THE MAGNETIC PROXY RECORDS IN THE EASTERN UKRAINE

N.P.Gerasimenko (Institute of Geography of Ukrainian Academy of Sciences, Volodymyrska, 44, Kyiv, 252003, Ukraine)
L.I.Vigilyanska(Inst.of Geophysics of UAS, Palladina, 32, Kyiv, 252142,Ukr.)

5 well stratigraphically subdivided sections of the Plio-Pleistocene have been subjected to the detailed paleomagnetic, lithological-pedological and palynological studies in the northern Dnieper and southern Donets regions of Ukraine. The investigation has been carried out by the climatostratigraphic (Veklich et al.,1984) and the magnetostratigraphic (Tretyak et al., 1993) scales of Ukraine and enables to trace an impact of the environmental changes on formation of rock magnetic signatures. In warmer conditions of southern region, all palaeosol units are known by much higher values of In,æ than loesses while in the north, Late - Mid-Pleistocene soils do not stand out sharply against a background of loesses.The stratigraphical position of the reversals, of Jaramillo, Blake, Goteborg and other events has been determined. In some cases, they are not strictly related to the same visible stratigraphic units. In southern region, the Brunhes /Matuyama is related to the lower part of the Shyrokin soil unit while in the northern - to the Illichivsk loess unit underlying the Shyrokin one.In the north,the soils of Shyrokin climatic optimum are characterized by deep downward migration of clay minerals and ultrafine magnetite overprinting the original magnetic polarity signature. Pollen spectra are in a discrepancy with soil type that also gives evidence of postsedimentary transformation by soil processes. The other examples will be given in the report.

FINE GRAINED MAGNETITE IN ADRIATIC HOLOCENE SEDIMENTS - THE INTERPLAY BETWEEN DETRITAL AND BACTERIAL SOURCES: THE RESULTS FROM EC PALICLAS PROGRAMME

Z.E Gibbs & K.D.Van der Post (Department of Geography University of Liverpool Liverpool L69 3BX. U.K
T Rolph (Geomagnetism Laboratory, Earth Sciences, University of Liverpool L69 3BX. U.K
F. Oldfield PAGES Baerenplatz 2 3011 Bern Switzerland

Away from sites close to major river or industrial inputs, and in sediments where neither tephra deposition or reductive diagenesis dominates the rock magnetic record, the magnetic properties of the Holocene sediments from the western and central Adriatic ar characterized by stable single domain (SSD) ferrimagnets. TEM images confirm that these sediments are rich in bacterial magnetosomes. The characteristic magnetic signature of these sediments (high χ_{ARM} relative to SIRM, χ, and $\chi_{FD\%}$,) is modified towards the top of each profile. Comparison with pollen records from the same cores shows that this reflects the increased input of eroded soil as a result of human activity. This inference is supported by the spatial changes in magnetic properties in recent sediment cores taken at different distances from the Po delta. The results as a whole lend support to the suggestion that careful measurements of χ_{ARM}/χ and $\chi_{ARM}/\chi_{FD\%}$ can help to discriminate between magnetosome-derived, fine grained ferrimagnets and those less exclusively SSD assemblages found in soils, weathered regolith and the eroded products derived from such sources. The results also suggest that subtle shifts in magnetic grain size within the SSD and transitional SSD-SP (superparamagnetic) range may influence reconstructed paleointensities of natural remanence (NRM), even where standard normalization procedures are used.

MAGNETIC CHARACTERISTICS OF THE ROCKS AS INDICATORS OF SEDIMENTOGENESIS EVOLUTION

A.N. Grishanov and E.A. Molostovsky (Geology Institute, Saratov University, 161 Moskovskaya st., Saratov, 410750, RUSSIA)

A clear reflection in petromagnetic characteristics was revealed of the conditions of terrigenous sedimentation in the East of the Russian Platform. The Riphean-Wendian terrigenous complex (TC) is represented mostly by red beds with moderate magnetic susceptibility ($k=2\text{-}4\ 10^{-4}$SI units), moderate natural remanent magnetization ($J_n=5\text{-}10\ 10^{-3}$A/m) and Kenigsberger ratio (Q) equal to 0.3-0.7. Magnetic minerals: hematite, getite, insignificant admixture of maghemite and magnetite. In the Devonian TC, sharp k increase (up to $5\text{-}25\ 10^{-4}$SI units), with $J_n=0.1\text{-}1.5\ 10^{-3}$ A/m) and $Q<0.1$, is associated with authigenic siderite mineralization. Two authigenic mineralizations are recorded in the Lower Carboniferous TC. For the first one (siderite), $k=3\text{-}25\ 10^{-4}$SI units, $J_n=0.5\text{-}2\ 10^{-3}$A/m, $Q<0.1$; for the second one (siderite-pyrrhotine), $k=20\text{-}80\ 10^{-4}$SI units, $J_n=10\text{-}800\ 10^{-3}$A/m, $Q=0.2\text{-}4$. The Upper Permian - Quaternary TC is characterized by sharp changes in rock magnetic properties: $k=0\text{-}100\ 10^{-4}$SI units, $J_n=0.5\text{-}200\ 10^{-3}$A/m. Magnetic minerals: terrigenous magnetite, hematite, maghemite, authigenic greigite. The magnetic-mineralogic characteristics presented above, reflect sedimentogenesis conditions changing from chiefly oxidizing (Riphean-Wendian TC) to reducing (Devonian TC) and sharply reducing, partially hydrogen-sulfidic ones (lower Carboniferous TC). In the Permian-Triassic, the conditions of sedimentation were substantially influenced by the Urals tectonic movements, in the Pliocene-Pleistocene - by eustatic fluctiations of the Caspian Sea. The work has been carried out with the RFFI financial support (grant 96-05-65443).

A STUDY OF ROCK MAGNETISM AND ENVIRONMENTAL MAGNETISM ON LAKE SEDIMENTS FROM HULUN LAKE AREA, CHINA

S. Hu and E. Appel (Institut für Geologie und Paläontologie, Universität Tübingen, Sigwartstr. 10, 72076 Tübingen, Germany)
L. Ji and S. Wang (Nanjing Institute of Geography and Limnology, Academia Sinica, 210008 Nanjing, China)

The Late Quaternary lake sediments, covering the period from 13 to 3 ka B.P., were sampled from the East Openout Mine in Hulun Lake Basin, Inner Mongonia, China. The sediments consist of sandy and muddy clastic deposits. Magnetic, sedimentological, mineralogical, chemical and biological parameters of the sediments were studied. Magnetite is comfirmed as the main contributor for magnetic susceptibility (k). The values of k are positively correlated with the total Fe content and Al_2O_3 content. Higher k values are related to muddy sediments with fine grain size, while lower k values are related to sandy sediments with coarse grainsize. Values of k are reversely correlated with frequency-dependent susceptibility (k_{fd}). Higher k_{fd} may indicate the existence of finer magnetic particles, but could also be due to lower contribution of paramagnetic minerals. Combined with the sedimentological results, k can be taken as a proxy to indicate the fluctuations of the water level. Higher values of k respresent a deeper water level. Compared with the results from total organic carbon, diatoms, pollen and spore, higher values of k mainly indicate warm and wet climate, while lower values correlate to dry and cold climate, although k is not very sensitive to some short-period climatic fluctuations.

THE ORIGIN OF FINE GRAINED FERRIMAGNETIC MATERIAL IN NW PACIFIC CARBONATE SEDIMENTS: THE SIGNIFICANCE OF CORRELATING TERRESTRIAL AND MARINE RECORDS.

Z.E.Gibbs & J Bloemendal Dept Geography University of Liverpool Liverpool L69 3BX United Kingdom
J W King Graduate School of Oceanography University of Rhode Island Narragansett RI02882. U.S.A.

The depositional sequence of the Chinese Loess Plateau represents one of the most comprehensive continental climatic records in the world, with depositional sequences spanning the past 2.4Ma. Deep sea core V21-146 lies 2500km downwind of China and provides an excellent sedimentary record of acolian flux, which in turn reflects continental climatic change. Previous attempts to correlate the record from this core with samples from the Chinese Loess Plateau have compared the degree of pedogenesis on the loess plateau with the aeolian flux record of V21-146 (Hovan et al 1989), and demonstrate a good correlation between the two records. However, using magnetic analysis to examine both the sedimentary sequence of the Loess Plateau and the terrigenous component of V21-146 it is possible to identify a stronger relationship. An excellent correlation is observed between the c record of the Loess Plateau and the ARM record of V21-146. This however raises the question of the origin of the fine grained ferrimagnetic component in the deep sea core. TEM images now support the hypothesis that the origin is in fact detrital, and is not driven by the insitu production of biogenic magnetites by magnetotactic bacteria. The results also show that the ARM is driven by the changes in ferrimagnetic grain size observed between glacial and interglacial periods.

MAGNETIC SUSCEPTIBILITY AS A PROXY PARAMETER FOR THE DETECTION OF POLLUTION OF SOILS AND SEDIMENTS - CASE STUDIES

V. Hoffmann (Institut für Allgemeine und Angewandte Geophysik, Universität München, 80333 München; Email: viktorho@-rockmag.geophysik.uni-muenchen.de)
M. Knab, E. Appel (Institut für Geologie und Paläontologie, Universität Tübingen, 72076 Tübingen; Email: Erwin.Appel@uni-tuebingen.de)

Recent studies have shown that under certain conditions magnetic susceptibility can be used as a proxy-parameter for the detection of pollutants like heavy metals or even PAHs in sediments or soils. Very often, spherical fly-ash particles containing a magnetite-like phase were found to be responsible for the enhancement of the magnetic signal. We present preliminary results of several case studies initiated in the area of south Germany and the northern alps: (i) Contamination of river-sediments due to deposition of fly-ash and clinkers, (ii) input and influence of traffic/ road dust to nearby soils, (iii) input of sewage/other effluences to river sediments. Preconditions for succesful studies using magnetic susceptibility for a fast mapping of polluted areas including detection of the possible cause are (a) a low background-signal and (b) isolated sources of pollution.

THE PALEOENVIRONMENTAL SIGNIFICANCE OF ROCK MAGNETIC PROFILES FROM THE LAC D'ANNECY, E. FRANCE

Y Hu (Department of Geography, University of Liverpool, Liverpool, L69 3BX, UK)
F Oldfield (Geography, Liverpool; present address PAGES, Bärenplatz 2, Ch-3011, Bern, Switzerland; 41-31-312-3133; e-mail: oldfield@-pageigbp.unibe.ch)
V Thorndycraft (Geography, Liverpool)

Results from a range of cores are used to illustrate the controls on the rock magnetic record in the sediments of this strongly calcareous lake system within the French Jura. Among the factors influencing the rock magnetic record, which spans the period from the Last Glacial Maximum (LGM) to the present day, are the following:- (1) changing sources of glacigenic material during the earliest stages of local deglaciation, (2) during the same period, cyclic deposition of clastic material with varying granulometry, (3) climatic shifts during the Late-Glacial period,(4) fluctuations in the balance between bedrock-derived, goethite-rich sediments and more strongly ferrimagnetic assemblages, (5) varying degrees of dilution by carbonates and organic matter during the Holocene period, (6) greigite formation during the late Holocene in response to increased organic productivity, (7) the impact of human activity on the catchment and resulting erosive unput, especially during the last 1000 years and (8), within this more recent time interval, single events reflecting major storms with high, soil-derived. clastic sediment input. The magnetic properties thus express climatic forcing in different ways during each period, but they provide a high resolution record of responses to short-term fluctuations and to extreme events.

MAGNETIC MINERALS AS INDICATORS OF REDOX POTENTIAL AND SALINITY VARIATION IN CASPIAN SEA LATE QUATERNARY

A.Jelinowska & P.Tucholka, Laboratoire de Physique de la Terre et des Plantes, URA CNRS-1369, Universit Paris Sud, Orsay, France.

The change in the magnetic mineralogy reveals an important change in the operation of the Caspian Sea system which mark the Late Pleistocene - Holocene transition. The presence of greigite indicates the brackish or fresh water conditions in Late Pleistocene with an anoxic bottom and thus a bad ventilation of the basin. Variation of the content and size of magnetic grains (ARM) corresponds to global climatic change as recorded in Greenland ice core and Chinese loess. The total length of the record may be estimated as 70 kyrs. Importance of the detrital material input to the basin and the low contribution of endogenic carbonates are indicated by other proxies. These results reflect most probably the higher Caspian Sea level during Late Pleistocene than present and an important erosion in its catchment area. During the isotopic stage 3 the greigite grains are significantly larger due probably to an increased salinity and thus lower level of water which is still badly ventilated. It means that corresponding regre ssion was less marked than that in Holocene. The transition to Holocene is marked by a stepwise disappearance of greigite and an appearance of detrital magnetite. This implies the stepwise establishment of a good ventilation and total oxygenation of water and bottom sediments in Holocene. This change occurs simultaneously with the increase of the endogenic carbonates and an important decrease of the detrital fraction proportion. This suggests a decrease of the erosion and/or reduction of the catchment area and decrease of the Caspian Sea level to its present value.

ROCK MAGNETIC SIGNATURE OF THE LAST INTERGLACIAL PERIOD RECORDED IN BULGARIAN LOESS-SOIL SEDIMENTS

D Jordanova (Geophysical Institute, Acad Bonchev Str , bl 3, 1113 Sofia, Bulgaria)
E. Oches (Institute for Rock Magnetism, Univ of Minnesota, Minneapolis, MN 55455-0219, USA)
N. Jordanova (Geophysical Institute, Acad. Bonchev Str., bl.3, 1113 Sofia, Bulgaria)
J. Evlogiev (Geological Institute, Acad Bonchev Str., bl. 24, 1113 Sofia, Bulgaria)

One particular point of this study consists in determining the contribution of viscous ferrimagnetic particles on the formation and significance of palaeoclimatic proxy record For that purpose the stability and time dependence of laboratory acquired VRM have been studied. To reveal the variations in concentration as well as the magnetic grain-sizes initiated by enhanced pedogenic processes or changes in eolian input, hysteresis parameters H_c, H_{cr}, σ_S and ratios M_{rs}/M_s, H_{cl}/H_c, χ_f/σ_S , σ_{arm}/σ_{IS} have been plotted for each 10^{th} cm along the profile. According to the results from low-temperature demagnetization of SIRM(20K,2.5T) as well as continuous thermal demagnetization of SIRM(300K,2T) up to 700°C and thermal demagnetization of composite IRM, the presence of SD, PSD and MD magnetite grains is evident. In the upper part of L1 unit the abundance of viscous ferrimagnetic particles points to relatively improved palaeoclimatic conditions at the end of the last Wurm stadial. The least weathered L2 unit is characterized by the lowest SP content, pointing to the minor role of pedogenesis.

MAGNETIC RECORDS OF CLIMATIC CYCLES IN MESOZOIC BLACK SHALE SUCCESSIONS

P. Kössler, E. Appel (Institut für Geologie und Paläontologie, Sigwartstr. 10, D-72076 Tübingen, Germany)

Magnetic susceptibilities of a Lower Aptian hemipelagic profile from the Vocontian trough (SE-France) indicate both long periodic and higher frequent variations of the ferrimagnetic mineral content. Susceptibilities of the alternating marl and black shale layers correspond to the intercalated bedding with maximum values in the black shales. Besides long periodic fluctuations of susceptibility could be identified. According to faunal evidence, constant values of IRM ratios indicate continuous sedimentation without clastic components delivered from secondary sources. Therefore it is supposed that variations in susceptibility are predominantly conditioned by effects of dilution which are caused by alternating biogenic and organic productivity. In contrast to these results, susceptibilities of Early Jurassic black shales from SW-Germany correlate with the content of siliciclastica and anorganic carbonates and therefore reflect the alternating detrital input. Nevertheless estimation of sedimentation rates suggests, that the magnetic susceptibility of the marl/black shale successions reflects climatic cycles induced by changes of the orbital parameters.

A PALAEOENVIRONMENTAL STUDY OF LATE-GLACIAL/EARLY HOLOCENE LACUSTRINE SEDIMENTS: EVIDENCE FOR SHORT TERM CLIMATIC CHANGE FROM HAWES WATER A MARL LAKE IN NW ENGLAND.

R. T. Jones N. Richardson (Dept Geography, Edge Hill University College, Ormskirk, Lancashire, England, L39 4QP)
J. D. Marshall (Dept Earth Science, University of Liverpool, P.O. Box 147, Liverpool, England, L69 3BX)
F. Oldfield (PAGES, Bärenplatz 2, CH-3011 Bern, Switzerland)
S. Nash (Dept Geography, Kingston University, Kingston upon Thames, London KT1 2EE)

Results are presented of a high resolution multiproxy study of Late-glacial lacustrine sediments from Hawes Water, a freshwater marl lake in Lancashire, England. Oxygen isotope analysis identified four periods of minor climatic deterioration, a first for the British Late-glacial. Three of the minor oscillations occurred during the Windermere Interstadial, the fourth in the Early Holocene. The short-lived decrease in the $^{18}O/^{16}O$ ratio at these points coincides with a temporary decline of the birch pollen curve, indicative of short -term climatic deterioration. Fluctuations in the mineral magnetic data (IRM $_{-40}$ / SIRM) show close correspondence to the shifts observed in the $^{18}O/^{16}O$ curve. These fluctuations possibly reflect changes in sediment source which may, in part, be climatically controlled. This offers the exciting possibility of using this magnetic parameter as a proxy for the $^{18}O/^{16}O$ analysis in such sediments.

MAGNETIC MAPPING OF FLY-ASH POLLUTION AROUND A POWER PLANT OF POČERADY, CZECH REPUBLIC

A. Kapička, E. Petrovský, (Geophysical Institute, Boční II, 141 31 Prague 4, Czech Republic)
K. Macháčková (Institute of Environmental Studies, Charles University, Prague, Czech Republic)
S. Ustjak (Research Institute of Crop Production Prague, Department of Ecotoxicology Chomutov, Czech Republic)

Measurements of magnetic susceptibility of surface soils around relatively isolated coal-burning power plant were used as a proxy method of outlining areas and directions of different pollution by fly-ashes. Magnetic susceptibility data obtained by field measurements were compared with the results of chemical analysis of soil samples. Preliminary results exhibit great angular and radial variability of surface soil magnetic susceptibility; directions of low as well as enhanced values can be easily identified. Apparently good relationship was found between magnetic susceptibility and contents of Cr and Co and partly Pb. Different aspects, affecting reliability of magnetic measurements ("geogenic" effect, value of chemical data obtained after leaching, etc.) will be discussed.

EVOLUTION OF MAGNETIC MINERALOGY IN VARIOUS WEATHERING ENVIRONMENTS.

MATHÉ P-E., ROCHETTE P., COLIN F., CEREGE, UM GECO-CNRS FU017, BP80, 13545 Aix-en-Provence cedex 04, France

The behaviour of magnetic mineralogy during meteoric weathering of well-characterized profiles have been studied in various environments.
In the lateritic systems studied, in Burkina-Faso and Cameroon, magnetic mineralogy is dominated by neoformed iron-bearing phases (goethite/haematite in particular) under humid tropical conditions. Two major processes can be distinguished on the bases of low-field susceptibility measurements. 1) Saprolitization induces low susceptibility values (c.a. 100 nm^3/kg.). 2) Ferralitisation in iron crusts enhances susceptibilities (≥500nm^3/kg) indicating traces of neoformed maghemite-like phases.
In recent weathering of a basalt flow in Morocco, under more aridic conditions, the magnetic mineralogy is dominated by inherited titanomaghemites. A model of selective dissolution is proposed. Moreover, high-field susceptibility profiles give evidences for the progressive changes of the magnetic speciation of iron with weathering, due to the transformation of primary iron-bearing silicates into neoformed iron phases. High-field susceptibilities of this neoformed fraction are in aggreement with the values obtained on a poorly crystalline Al substituted synthetic goethite.
The results show the interest of applying magnetic method to weathering environements, where other classical methods partly fail to detect traces of iron-bearing phases and their evolution.

PALEOMAGNETIC VARIATIONS AS INDICATORS OF PALEOCLIMATIC CHANGES AND FLUCTUATIONS OF THE LEVEL OF THE CASPIAN SEA IN THE PLIOCENE

E.A. Molostovsky, A.Yu. Guzhikov, (Geology Institute, Saratov University, 161 Moskovskaya st., Saratov, 410750, RUSSIA)

Complex research of the sections was carried out in the wells penetrating the Pliocene (Akchagylian and Apsheronian regional stages) over the territory of the North Cis-Caspian and Middle Volga regions. Authigenic pyrrhotine and greigite are the main magnetization carriers in the rocks. Variations in their concentrations over stratigraphic sections are clearly documented by means of petromagnetic characteristics (magnetic susceptibility - k, etc.). Sulfide-forming processes in the sediments are most intensive when two factors are combined: high sea level, favourable for creation of stagnant, reducing settings, and climatic optimum, with sharp increase in the amount of vegetable organic matter. It is supposed, that variations in scalar magnetic characteristics adequately reflect fluctuations of the level of the Caspian Sea as well as paleoclimatic changes. Analyses of gamma logs, paleontologic, palynologic, geochemical and lithologic-mineralogic data confirm this conclusion and show petromagnetic variations to provide the most expresse and clear records of paleogeographic events compared to the data of other methods. The work has been carried out with the RFFI financial support (grant 96-05-65443).

MAGNETIC MONITORING IN COPPER-SMELTING WORK POLLUTED CATCHMENT: PRELIMINARY STAGE

A.A.Nulman, S.E.Borich, A.E.Rytsk (Institure of Geophysics, Amundsenstr.100, 620016 Ekaterinburg, RUSSIA)

During last two years studies of possibility to use magnetic susceptibility (MS) measurements for control of aeolian heavy metals contaminations in zones influenced by copper-smelting works are carried out in the Middle Urals. It is expedient to apply the magnetic method to those environmental components, which have small own MS.To detect winter contaminations the MS studies of melting snow samples are carried out.The investigation of MS of plants is conducted, as an attempt to create a method of summer heavy metal pollution monitoring.Most of samples were collected in experimental ground (25km2) in catchment of drinking pond polluted by copper-smelting work. There are 15 sites of sampling in the ground.Three of them were sampled twice(in 1995 and in 1996). Using different methods of snow sample preparing we extracted different quantities of dust from melting snow solutions. Correlations between magnetic parameters and heavy metals contents determinated by spectrochemical methods were reseached in dusts and in solutions.To begin magnetic monitoring we have selected method of quick melting, which allows to extract the most quantity of heavy metals with dust from solution.The coefficients of leanear correlations between a derivative of magnetic moment dM/dH of dust samples and Cu, Pb, Zn quantities in them were 0.94, 0.88 and 0.86.

SOME COMMON RELATIONS BETWEEN MAGNETIC SUSCEPTIBILITY AND PALAEOCLIMATIC PARAMETERS IN SEDIMENT CORES OF EAST-EUROPEAN LAKES (RUSSIA).

D.K.Nurgaliev, A.S.Borisov, B.V.Burov, P.G.Jasonov, D.I.Khasanov, V.T.Shalandina, N.N.Nikitina (Faculty of Geology, Kazan University, 420008, Kazan, RUSSIA)
F.Heller (Institut fur Geophysik, ETH Zurich, CH-8093, Switzerland)
I.Hajdas(Institut fur Teilchenphysic, ETH Zurich, CH-8093, Switzerland)

Holocene magnetic susceptibility records have been obtained from sediment cores of Russian lakes: Onega, Lacha, Kubenskoye, Galichskoye, Kandrykul and Aslikul. The susceptibility logs have been correlated between cores from each lake and, in some cases, also between lakes. Different palynological, litological, magnetic, paleomagnetic parameters have been used for the investigation. Palcotemperature and paleoprecipitation curves have been reconstructed using palynological data. Relative sedimentation rate have been reconstructed using correlation of magnetic susceptibility logs between cores. Method for determination the clear palaeoclimate sygnal from records of magnetic susceptibility will also be discussed.

THE CONTAINING OF HEAVY METALS AND MAGNETIC PROPERTIES OF SOILS IN KAZAN SITY (RUSSIA).

Natalya Nikitina , Ruslan Rakhmatullin (Faculty of Geology, Kazan University, 420008, Kazan, RUSSIA)

The samples of the soil from industrial regions of Kazan Sity (Tatarstan, Russia) have been investigated. The magnetic susceptibility of collected samples were measured by the laboratory device KL-1; ferromagnetic minerals were determined by thermomagnetic method and the relations of Fe^{2+} and Fe^{3+} were detected. Magnetic-mineralogical researchings consisted of: the differencial thermomagnetic analys by the inductive magnetization; the differencial thermomagnetic analys by the different types of remanent magnetization; coerective spectras. Atomic-absorbtial analys was used to get general containing of Fe and overall containing of heavy metals.

During this researching work there have been obtained the relations between magnetic susceptibility and heavy metalls containing for some kinds of soils.

USING OF MAGNETIC SUSCEPTIBILITY AS PALAEO-CLIMATE MARKERS IN PERMIAN CLAYS (EAST-EUROPEAN PLATE, RUSSIA).

D.K.Nurgaliev, R.S.Mukhamadiev, A.Sh.Yakupov, N.Ya.Shabalin (Faculty of Geology, Kazan University, 420008, Kazan, RUSSIA)

It have been investigated data of well log measurements on magnetic susceptibility(MS), natural gamma radiation (NGR), SP and electrical resistivity in permian clay-containing red beds. There are different types of relation between these parameters in sections. Thermomagnetic analys of samples from sections showed correlation between values of MS changes and contents of γ-Fe_2O_3, α-Fe_2O_3, Fe_3O_4. It was obtined different origin of magnetic material in these sediments: from palaeosoil-horizons (high content of γ-Fe_2O_3, high values of MS, NGR in clay-content rocks), from far situated igneous rocks (oxydited Fe_3O_4, assosiation Fe_3O_4 - γ-Fe_2O_3, high content of sand component), from permian sedimentary rocks (hematite, low values of MS, high values of NGR in clay-content rocks). This model have been used for correlation of "climate optimums" in well-sections.

MULTI-PARAMETER ROCK MAGNETIC EVALUATION OF LOESS-PALEOSOL SEQUENCES LINKS MAGNETIC SUSCEPTIBILITY VARIATIONS WITH PALEOCLIMATE

OCHES, Eric A., and BANERJEE, Subir K., Department of Geology & Geophysics and Institute for Rock Magnetism, University of Minnesota, 310 Pillsbury Dr. SE, Minneapolis, MN 55455, USA.

Multi-parameter rock magnetic investigations of loess-paleosol sequences in China, central and eastern Europe and North America demonstrate the complex relationship between magnetic susceptibility (MS) variations and paleoclimate during the last interglacial-glacial climatic cycle. MS, used alone, can be a misleading proxy for paleoprecipitation during periods of interglacial and interstadial soil formation. However, when evaluated in conjunction with ARM and hysteresis parameters, specific elements of ferromagnetic grain size, concentration, and mineralogy can be identified which, in turn, can be explained in terms of depositional and post-depositional climate-modulated processes. Calibration of rock magnetic proxies with these processes is confirmed using independent nonmagnetic data. Several models can be invoked to explain stratigraphic MS patterns in loess sequences, including wind-driven eolian grain size variations, moisture-controlled diagenetic leaching processes, and insitu production of ultra-fine magnetite and maghemite grains. No single rock magnetic - paleoclimate model can be uniformly applied to all loess sequences; distinct regional or site-specific models must be developed independently.

ORIGIN OF SEABED SUSCEPTIBILITY SIGNAL VARIATIONS IN COASTAL STUARINE-LIKE SEDIMENTS OF NW SPAIN

D Rey, O Pazos, N López-Rodríguez, F Vilas, B Rubio, & L Gago-Duport
Dep. Recursos Minerais e Medio Ambiente, Univ. de Vigo, 36200 Vigo, ES
M L Osete & M F Bogalo
Dep. Geofísica, Universidad Complutense, 28040 Madrid, ES

Measurement of low field susceptibility of over two hundred samples of surficial (top 10 cm) seabed sediments of the Rias of Vigo and Pontevedra (1 per square km) showed characteristic spatial variations patterns. The susceptibility value correlated well with existing data on their grain-size distribution, OM and carbonate content. Samples were then split into their coarse and fine fractions and susceptibility measured separately for each fraction This resulted in new and very revealing spatial variability patterns suggesting a link between sediment provenance and origin of the magnetic signal. To further evaluate this relationships, the available sedimentological data were completed with major elements analysis and XRD of the clay fraction. In addition various magnetization curves (IRM, back field, ARM and hysteresis loops) were obtained for selected specimens.
The combined analysis of these data showed that the spatial variability of the susceptibility observed in the different granulometric fractions can be spatially related to: (a) the continental influx, (b) sediment and water transport and exchange between the Rias and the adjacent shelf, (c) the effect of seasonal upwelling on primary production and sediment dynamics, (d) antropogenic solid particulate pollution.

CLIMATIC VARIATIONS IN THE UPPER PLEISTOCENE LOESS SEQUENCE AT ACHENHEIM (ALSACE, FRANCE).

D. D. Rousseau, (Université Montpellier II, Paléoenvironnements & Palynologie, UMRS CNRS 5554-Inst. Sci. Evolution, case 61, pl. Bataillon 34095 Montpellier cedex 05 France).
BIMACEL group (EC grant EV5V-0298, Theme Climatology et Natural Hazards of Program Environment 1991-1994).

The new susceptibility record of the last climatic cycle from the loess series at Achenheim Alsace indicates that in fact this series is incomplete. According to the characterization of a Marker sub-unit which is interpreted as corresponding to dust storms at a continental scale, the analysis of magnetic susceptibility shows that the loess deposition occurred during isotope stages 4, 3 and 2 in agreement with the GRIP dust record. In both records, the intensity of dust storm is maximum during MIS 4 and 2 while reduced during stage 3. The new chronology derived from the correlations between the loess series and the GRIP curve indicates that the variations in MS are not local but correspond to more global events as several interstadials can be recognized.

ANALYSIS OF DIFFERENT CLIMATE PROXIES IN THE WESTERN AND CENTRAL LOESS PLATEAU, CHINA

M.Sartori and F. Heller (Institut für Geophysik, ETH-Hönggerberg, CH-8093 Zürich, Switzerland)
M.E. Evans (Intitute of Geophysics, Metereology and Space Physics, University of Alberta, Edmonton, Canada, T6G2J1)
Han J. (Institute of Geology, Academia Sinica, Beijing 100029, China)
A. Tsatskin (Zinman Institute of Archaeology, University of Haifa, Israel)
J. Beer (Umweltphysik, ETH-Zürich, c/o EAWAG, CH-8093 Dübendorf, Switzerland)

Two new loess/paleosol sequences in Xiagaoyuan near Jinyin (Western Loess Plateau) and in Huangzhou near Huangling (Central Loess Plateau) have been sampled. Different climate .proxies have been measured in detail for the paleosol S1 in both sections. They are hepful in order to reconstruct different climatic conditions during sediment deposition and pedogenic tranformation. A detailed sedimentological study on several samples collected emphasizes the climatic and environmental variability of the Western and Central Plateau. The isotope content (Be-10, U/Th) in the loess/palesol sequences is related to precipitation variation in time, and change in grain size distribution show cyclic climate changes during the last interglacial. These processes also control strongly the rock magnetic properties: low field susceptibility and its frequency dependence, anhysteretic remanent magnetisation and hysteresis parameters.

MAGNETIC AGE MODELS IMPLY MAJOR SEDIMENTATION EVENT IN THE SUBTROPICAL SOUTH ATLANTIC OCEAN 520-540 KY BP

F. Schmieder, T. von Dobeneck, M. Breitzke & U. Bleil (FB Geowissenschaften, Universität Bremen, Postfach 330 440, D-28334 Bremen, Germany)

Reversal magnetostratigraphy and astronomical tuning of magnetic susceptibility records were applied to establish high resolution chronostratigraphies for 12 deep-sea sediment cores from the subtropical South Atlantic Ocean. The 30°S coring transect covers Rio Grande Rise, mid-Atlantic Ridge and Walvis Ridge in water depths ranging between 2900 and 4500 m. The gravity cores are generally characterized by very low average sedimentation rates of less than 1 cm/ky, typical for this carbonate dominated subtropical oligotrophic area.
The age models indicate increased sedimentation rates near isotopic stage 13.3 (524 ka). Below, different unusual lithologies were encountered including finely laminated layers, hiati and, in two cases, thick diatom (*Ethmodiscus Rex*) ooze layers (38 cm and 124 cm). A quick burial seems to be responsible for the preservation of these readily dissolvable siliceous fossils. Both rock magnetic and acoustic analyses testify sharp systematic changes within the sediment assemblage.
All magnetic susceptibility records clearly document the transformation from an obliquity (41 ky) to a more eccentricity (100 ky) dominated signal between 1200 and 500 ka, a paleoclimatic enigma known as "mid-Pleistocene revolution". According to the evolutionary spectral analysis of our data, complex low-frequent fluctuations turn into a stable 100 ky cycle near the event described above.

MAGNETIC SUSCEPTIBILITY AS A TOOL FOR MAPPING OF HEAVY METAL CONTAMINATION OF SEDIMENTS AND SOILS: CASE STUDIES FROM STYRIA, AUSTRIA

R. Scholger (Institut für Geophysik, Montanuniversität Leoben, Paläomagnetiklabor, Gams 45, 8130 Frohnleiten, Austria)

Samples from the soil store at the Styrian Agricultural Laboratory were subsampled and measured for magnetic susceptibility in order to investigate the applicability of magnetic methods for contamination mapping. The samples originated from various environments with different sources of heavy metal anomalies (mining, steel production, street dust, pestizides, geology). Depending on the different ferromagnetic contaminants, the correlation of susceptibility with certain heavy metals was significant within specific areas. Some of the case studies showed strong correlations of susceptibility with either As, Cd, Cr or Pb. Based on a comparison of all samples under investigation it was possible to discriminate between industrial anomalies and anomalies derived from particular geological circumstances. Results from several case studies will be presented together with the first draft map of the magnetic susceptibility of topsoils across Styria, which is based on 455 sampling sites from a 4 x 4 km grid. The measurements of over 2000 samples from the soil store, still in progress, are carried out using a Bartington MS2C loop sensor.

ROCK MAGNETIC/SEDIMENTOLOGIC PROXIES FOR PALEOCLIMATIC CHANGE IN UPPER PALEOZOIC LOESSITE

G.S. Soreghan (Geology, University of Oklahoma, Norman, OK 73019, USA)
R.D. Elmore, B. Katz, and S. Banerjee (affiliation as above)

Recent recognition of upper Paleozoic loessite deposits in western North America raises the possibility of using magnetic methods to investigate terrestrial paleoclimate in a very ancient system. The Pennsylvanian-Permian Maroon Formation in Eagle basin (Colorado) consists locally of loessite. Reddish-orange loessite beds (m scale) are commonly separated by reddish-brown partings. Selected reddish-brown partings bear sedimentologic evidence of incipient pedogenesis. Bulk magnetic susceptibility through a section encompassing several loessite/paleosol(?) alternations varies by an order of magnitude: lows correlate to unaltered loessite, and highs to the darker-colored, probable paleosols. Detection of the Verwey transition in samples of both high- and low susceptibility confirms the presence of magnetite. Hysteresis loops of both high and low susceptibility samples exhibit wasp-waisted behavior, indicating a mixture of high- and low coercivity material. Normalized ferrimagnetic susceptibility of a high susceptibility sample significantly exceeds that of a low susceptibility sample, suggesting a greater contribution of SP magnetite in the former. Demagnetization of the NRM reveals late Paleozoic components residing in magnetite and hematite. These results suggest that, analogous to Quaternary loesses, magnetic susceptibility variations in the Paleozoic loessite may reflect pedogenesis related to paleoclimatic fluctuations.

GREIGITE BOUND SULPHUR CONCENTRATIONS MEASURED BY MINERAL MAGNETIC ANALYSIS: A NEW METHOD OF OBTAINING C/S RATIOS AND TO IDENTIFY LAKE BASIN ISOLATION

I. F. Snowball (Geological Survey of Finland, Betonimiehenkuja 4, FIN-02150 Espoo, Finland)

Ferrimagnetic greigite (Fe_3S_4) is normally classified by geochemists as an unstable acid-volatile sulphide (AVS) or as an intermediate and temporary product of sulphate reduction (with pyrite, FeS_2, forming the end product). However greigite is easily detected by magnetic analyses and is frequently found preserved in sediments of variable age and origin. During a study of Late-Weichselian sediments in southern Sweden high concentrations of greigite were observed in sedimentary basins that were eventually isolated from a marine environment. The greigite (of single-domain magnetic grain size) is present in marine (brackish) sediments with low values of total organic carbon (TOC) and freshwater sediments with high values of TOC. By subtracting the magnetic signal carried by detrital minerals it was possible to quantify the sulphur bound as greigite (S_{greg}), without resorting to elaborate geochemical analyses (although total sulphur was measured). The ratio TOC/S_{greg} successfully discriminates between marine (brackish) and freshwater environments. The study illustrates the capabilility to obtain quantitative geochemical data at a high resolution from mineral magnetic measurements.

MAGNETIC SUSCEPTIBILITY AND HEAVY METALS CONTENT IN FLY ASHES AFTER HARD AND BROWN COAL COMBUSTION.

Z. Strzyszcz (Institute of Environmental Engineering Polish Academy of Sciences, ul. M Skłodowskiej-Curie 34, 41-819 Zabrze, Poland)
T. Magiera (Institute of Environmental Engineering Polish Academy of Sciences, ul. M Skłodowskiej-Curie 34, 41-819 Zabrze, Poland.

The investigation of magnetic susceptibility in soils of southern Poland revealed, that its increase is due to immission of air pollutants, such as fly ash, metallurgical dust and cement dust. Metallurgical dust and cement dust have, usually a local reach, which depends on height of the emitter and size of emitted dust particles. In 1995 in Poland 108 Mt. of hard coal and 70 Mt. of brown coal have been burnt, which produced a significant amount of fly ashes. They show a quite high fluctuation in the magnetic susceptibility and it is resulted from different iron content in hard coals. Depending on origin (coal bed) and amount of ashes, iron content ranges from 6.3 to 27.5% Fe. Not whole iron shows ferrimagnetic properties but only that part which is originated from iron sulphides (pyrite, marcasite). Heavy metals, such as Zn, Pb, Ni and Cu are accompanied by those two minerals and their amount in hard coal ranges from 3.4 to 198.9 mg/kg, 3.3-63.0 mg/kg, 2.0-28.3 mg/kg and 6.3-68.9 mg/kg, respectively. Correlation coefficients (r), between total sulphur content in hard coal and heavy metals content are as follow: 0.56 for Zn, 0.57 for Pb, 0.49 for Ni and 0.89 for Cu (number of samples = 19).

MAGNETISM OF LOESS-PALEOSOL SEQUENCES ALONG THE CLIMATIC GRADIENT FROM THE CENTRE TO THE SOUTH WEST OF THE RUSSIAN PLAIN

E. Virina (Moscow State University, 119899 Moscow, Russia)
T.S. Gendler (UIPE, B. Gruzinskaja 10, 123810 Moscow, Russia)
A. Tsatskin (University of Haifa, Haifa 31905, Israel)
F. Heller (ETH Zürich, CH-8093 Zürich, Switzerland)
J. Hus (Centre de Physique du Globe, B-5670 Dourbes, Belgium)
E.A. Hailwood (Southampton University, Southampton SO9 5NH, UK)

Detailed magnetic susceptibility (χ) measurements were conducted at the sites Strelitsa (Voronezh), Kolkotova Balka (Tiraspol) and Roxolany (Odessa). Numerous pedocomplexes (PK) show enhanced χ compared to the intercalated loess sediments. The spatial pattern of χ values in modern soils decreases from more humid, forest-steppe chernosems (Strelitsa) to sub-humid calcareous chernosems (Roxolany, Tiraspol). However, χ of a given pedocomplex shows a different trend and a complex pattern across the plain from north to south. For example, the PK corresponding to oxygen isotope stage 13 has the highest χ at Roxolany, corroborating with strong bioactivity and accumulation of humus under a balanced regime of precipitation and evaporation. Such conditions appear to be optimal also for the formation of superparamagnetic magnetite, which becomes reduced on increased precipitation and leaching (as in the Voronsky PK at Strelitsa) or on excessive waterlogging (as in the PK just above the flood-plain alluvium in Kolkotove Balka). The spatial pattern of χ in the paleosols suggests that the magnetic record is controlled by the nature of pedogenesis, depending on both bioclimatic and local geomorphological factors.

ENVIRONMENTAL CHANGES IN THE HOLOCENE DEDUCED FROM ROCK MAGNETIC PROPERTIES OF LAKE SEDIMENTS FROM THE WEST EIFEL (GERMANY).

H. Stockhausen (Institut für Geophysik, Corrensstr. 24, D-48149 Münster, Germany)

Paleoenvironmental changes in the Holocene have been investigated from detailed rockmagnetic analysis of mainly organic rich sediments from three german maar lakes. The lakes are supposed to have experienced nearly identical paleoclimatic and paleomagnetic conditions thus allowing a comparison of different rockmagnetic parameters assumed to reflect paleoclimate and relative paleointensity, respectively. Rockmagnetic parameters indicate that ferromagnetic concentration variations mainly depend on human activity and climatic changes in cases where detrital titanomagnetite of aeolian origin dominates the magnetomineralogy. The climatic signal of concentration variations is more difficult to read if minerals are authigenic or provided by a tributary. The proportion of high to low coercive minerals (*S*-Ratio) seems to be an appropriate paleoclimatic indicator for one lake where grain size variations are minor. Results show that rockmagnetic paleoclimatic indicators are not valid for all three lakes simultaneously. Relative paleointensity estimates have been obtained by various normalization methods of natural remanence. Different methods show reasonable within lake agreement but between lake discrepancies render it questionable if relative paleointensity has been recorded.

ROCKMAGNETIC AND GEOCHEMICAL ATTEMPTS TO CORRELATE RECORDS OF TWO HOLOCENE CORES AND IT'S ENVIRONMENTAL IMPLICATION

F. Tamrat, D. Williamson and M. Taieb
Laboratoire de Géologie du Quaternaire, CNRS-CEREGE, BP80, 13545 Aix-en Provence, France.

Comparison of rock magnetic records have been carried out on two piston cores taken from the Ziway-Shala basin (lake Abiyata and lake Langano, Ethiopia) to show how quickly closed-basin transported sediments responded to variations in regional climate, and how this response was recorded by the lacustrine deposition of magnetic grains. Several standard cubes were sampled from the piston cores for paleomagnetic, rock-magnetic and geochemical analyses. The reliability of the geomagnetic records being tested on several levels using alternating field (AF) and thermal demagnetisation (Th). Beside correlation between the two cores using ^{14}C AMS dates, magnetic susceptibility (χ) and intensity of remanence profiles provide good core correlations. Such correlation has been also tested on major and trace elements of volcanic glass shard horizons using a CAMECA MS 46 Microprobe. Previous results of detailed geochemical, sedimentological, palynological and diatom studies indicate that the Ziway-Shala basin was highly responsive to high (10^1-10^2 yr) and low-frequency (10^3 yr) climate changes during the Holocene. Therefore, magnetic susceptibility (χ) changes, which measures the concentration of strongly magnetic particles (magnetite, greigite etc.) in the sediment, closely correspond from one lake to the other one and suggest a synchronous changes in biogenic production during the Holocene.

MAGNETIC PROPERTIES OF LEACHING ZONES IN HYDROMORPHIC SOILS (GLEYSOLS)

R.S. Zergenyi, L. Lanci and A.M. Hirt (Institut fuer Geophysik, ETH-Hoenggerberg, CH-8093 Zuerich, Switzerland)
P. Luescher (Site Science, Eidg. Forschungsanstalt fuer Wald, Schnee und Landschaft, CH-8903 Birmensdorf, Switzerland)

The magnetic properties of a gleysol were examined at several type- profiles in Switzerland in order to investigate Fe transport in the leaching process. The upper 40 cm of the gleysol profiles consist of an organic horizon (L, F, H) and a mineralogic horizon, which can be subdivided in albic and spodic material. Mass susceptibility (x) ranges from 3.7-44.8e-8 m3/kg where a minimum occurs at the boundary between the H and the mineralogic horizons. x increases regularly from the albic to the spodic material. Low temperature experiments suggest that the paramagnetic minerals dominate x. IRM acquisition indicates that a low coercivity mineral is present throughout the profile. A high coercivity mineral is found in the mineralogic horizon and its concentration increases with depth. Oxalate and dithionate- citrate-bicarbonate extractions were used to monitor the amount of poorly crystalline and free Fe in the soils. We show that magnetic measurements combined with geochemical methods can provide information about pedogenic processes ocurring in leaching.

SE15 Rock- and palaeomagnetism and environmental magnetism

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PALEOMAGNETISM OF CENOZOIC VOLCANIC PIPES OF MINUSINSK DEPRESSION (RUSSIA)

V.Yu.Bragin, K.D.Litasov and V.G.Mal'kovets (United Institute of Geology, Geophysics & Mineralogy, Siberian Brunch of Russian Academy of Sciences. Universitetsky ave.3, Novosibirsk, 630090, Russia).

Cenozoic volcanic pipes of Minusinsk depression rich of mantle xenolites and are probably related to the 'hot spot' near the Baikal Lake (Rasskazov.1994, Yarmoluk et. al, 1994). The first paleomagnetic data were obtained from 4 pipes (42 samples) with K-Ar and Sr/Sr ages 65-49 Ma (Zubkov et.al.,1989). All the 4 pipes demonstrate high temperature ChRM component of reversed polarity with average direction D=177.6, I=-62.3, k=237.5, a95=6. However, some samples from Bele pipe demonstrate another direction (D=243.7, I=-56, k=323.2, a95=5.1). Corresponding paleopoles of both directions are statistically differ from the APWP of Eurasia (Besse, Courtillot, 1991; Enkin et. al, 1992). Paleomagnetic poles from basaltic rocks of near-Baikal region (see Khramov database) are consistent with the first of Minusinsk poles or lie along the great circle between them. This data call into question of implementation of Eurasian APWP to Northern Asia.

VARISCAN OVERPRINTS AND EVOLUTION OF CENTRAL EUROPE IN CARBONIFEROUS - PERMIAN TIMES

J.B. Edel (Ecole et Observatoire de Physique du Globe, URA 323, 5 rue Descartes, 67084 Strasbourg Cedex, France)

Extensive paleomagnetic studies of Late Proterozoic to Early Permian metamorphic, plutonic, volcanic and sedimentary units from various areas of the Variscan belt (Armorican Massif, Central Massif, Vosges, Black Forest, Odenwald, Spessart, Bohemian Massif and Sudetians) have demonstrated that at least 80% of the magnetic records consist of overprints. Contrary to the common thought, the situation is not hopeless. Due to various - composition of rocks, - magnetic mineralogy and - stratigraphic positions, overprints were acquired at different stages of the tectono-magmatic, metamorphic and hydrothermal evolution of the Variscan belt. In pre-Namurian units up to 6 groups of directions corresponding to different overprinting phases were isolated. Part of them could be correlated with primary results from younger intrusive or extrusive. VGPs of overprints and when available, of primary magnetizations delineate APWPs which from the Visean to the Early Jurassic are very similar for the different massifs. These APWPs allow to reconstruct the geotectonic evolution of the belt. Subsequently to the Late Visean tightening phase, from the Armorican Massif in the West to the Sudetians in the East, the motions of the investigated massifs are the same. A succession of three clockwise rotations with a total amount of about 140° affected the belt during the Latest Visean to Middle Permian time-span. The first occured at the end of the Sudetian phase and was the most important (80°). After suturing with northern Europe, the next rotations were likely common.

PALEOMAGNETIC EVOLUTION OF THE EUROPEAN PLATE FROM THE VARISCAN CONVERGENCE TO THE ATLANTIC RIFTING

J.B. Edel (Ecole et Observatoire de Physique du Globe, URA 323, 5 rue Descartes, 67084 Strasbourg Cedex, France)

Recent paleomagnetic data from Permian to E. Jurassic units of NE France and SW Germany led to the revision of the Apparent Polar Wander Path (APWP) of Europe and to better constrain the geodynamical evolution of the plate. New results from Carnian marls, Rhaetian sandstones and Hettangian limestones shift the Late Triassic-Early Jurassic loop of the previous APWPs by 25° to the west. The loop started at the Rhaetian-Hettangian boundary and ended in the L. Lias. Two prominent overprinting phases affected part of the pre-Jurassic series, including Carboniferous units, one in the upper Permian, the second in the Lias. The revised APWP involves the following plate motions. After the late Alleghanian tectonic phase which marks the end of the clockwise rotation of Variscan Europe and, consequently the end of the Variscan orogeny, the European plate rotated counterclockwise during 70 Ma, up to the latest Trias, with a nearly constant rate of rotation of the declination by 1.4°/ Ma. The S-N drift in latitude by 35° which has already began in the Mid-Carboniferous, remained regular up to 203 Ma with a constant rate of 3.4 cm/year. Around 203 Ma, this regular northward drift stopped, probably because of a collision somewhere in the North of Eurasia. In the E. Lias, the plate underwent a rapid counterclockwise rotation around an Eulerian pole located in NE Asia. This motion was probably responsible for the intraplate fracturing of Pangea which led to the Atlantic Ocean and the Neo Tethys and to the intrusion of numerous doleritic dikes along both sides of the future rift. Hydrothermal alteration associated with fracturing led to the large-scale overprinting observed in NE France and SW Germany.

ROCK MAGNETISM OF DEFORMED ROCKS FROM LAGONEGRO BASIN (SOUTHERN APENNINES, ITALY)

P. R. Gialanella, L. Ferranti & A. Incoronato (Dipartimento di Scienze della Terra, University of Naples "Federico II", I-80128 Naples, Italy)
F. Heller (Institut für Geophysik, ETH Zürich, CH-8093 Zürich, Switzerland)

Unusual rock magnetic properties have been found in several sites of a sector of Lagonegro nappe (Southern Apennines, Italy). This area is constituted by an anticline of Upper Triassic limestones which have been overthrust by Middle Triassic marls. The anisotropy of magnetic low field susceptibility varies from 2% to 40% at different sites of the anticline and shows a clearly inverse sedimentary fabric in the limestones of the central part of the structure. A normal magnetic fabric and weak anisotropy (<5%) characterise the overlying marls. The dependence of susceptibility on temperature and alternating field frequency results from a strong contribution of superparamagnetic minerals (SP) in the deformed limestones and from paramagnetic minerals in the marl samples. Evidence of significant SP magnetite fraction is also observed during acquisition of isothermal remanent magnetisation at room temperature and liquid nitrogen temperature. The variable magnetic behaviour of the carbonate rocks can be linked to multiple episodes of non-coaxial tectonic deformation revealed by structural analysis.

PALEOMAGNETISM OF FOUR SW BULGARIAN PLUTONS: 40° CRETACEOUS CCW ROTATION AND SUBSEQUENT 10° TERTIARY CW ROTATION

H. Haubold[1]
H.J. Mauritsch[1]
I. Zagorcev[2]
A. Harkovska[2]
R. Scholger[1]
K. Kourtev[2]
A. Lulo[3]

[1] Paläomagnetiklabor Gams, Montanuniversität Leoben, Gams 45, A-8130 Frohnleiten, Austria
[2] Geological Inst., Bulgarian Academy of Science, Acad. Bonchev-Str., Bl 24, 1113 Sofia, Bulgaria
[3] Geological Centre Tirana, Blloku 'Vasil Shanto' L. 9, Tirana, Albania

Although in the last two decades, paleomagnetism has made valuable contributions as to the structural development of the Balkan peninsula, only few reliable paleomagnetic data have been reported from Bulgaria.

Samples from the upper Cretaceous Bezbog and Dautov Plutons (SW Bulgarian Pirin Mountains) carry characteristic magnetizations indicating approximately 40° counterclockwise rotation, whereas the magnetizations of samples from the Paleogene Teshovo and Central Pirin Plutons (also Pirin Mountains) imply small (some 10°) clockwise rotation.

Our results from the upper Cretaceous plutons confirm previous work conducted in N Greece and, thus, suggest that the study area was attached to the African Plate during the upper Cretaceous, as was N Greece. Moreover, our Paleogene declination values are in accord with results from N Greece, too. However, surprisingly, we did not observe anomaleously shallow inclination values, although such shallow inclination values were previously reported from Tertiary rocks from the entire general Aegean region.

HIGH-RESOLUTION MAGNETOSTRATIGRAPHY ACROSS THE JURASSIC/CRETACEOUS BOUNDARY STRATA IN THE TETHYAN REALM: RESULTS AND PROSPECTS

V. Housa, M. Krs, M. Krsova, O. Man, P. Pruner and D. Venhodova (Geological Institute of the Academy of Sciences of the Czech Republic, Rozvojova 135, 165 00 Prague 6 - Lysolaje, Czech Republic)

The aim of our studies is correlation of biostratigraphic scales of the Jurassic/Cretaceous (J/C) boundary strata in the Tethyan and Boreal realms by means of magnetostratigraphy. In the first step, high-resolution (HR) magnetostratigraphic calibration of the biostratigraphic scale based on calpionellids is carried out. In the next step, magnetostratigraphic calibration of the Tethyan ammonite scale will be carried out close to the J/C boundary. Our team selected three localities for HR magnetostratigraphic and biostratigraphic studies. The locality of Brodno near Zilina (Western Carpathians, Slovakia) was found suitable for precise magnetostratigraphy covering the magnetozones M21 to M17, incl. two narrow reverse subzones located in the magnetozones M20n and M19n. The most significant calpionellid event characterizing changes at the base of the standard zone Calpionella alpina and used as a provisional J/C boundary in the Tethyan realm was located just above the middle of the magnetozone M19n. The next two localities are located in the Bosso Valley (Umbria, central Italy) and Carcabuey (S. Spain). Exact biostratigraphic correlation of the J/C boundaries between the Tethyan and Boreal realms is impossible due to lack of common index species and poorly developed biostratigraphic record. An alternative method of identifying chronologically identical sections may be offered by HR magnetostratigraphy.

AMS INDICATED POST-CRETACEOUS ROTATIONS IN THE INNER WEST CARPATHIANS: CHALLENGE FOR PALAEOMAGNETISM?

F. Hrouda (AGICO Inc., Box 62, CZ-612 46 Brno, Czech Republic)

The magnetic fabric is nearly coaxial in metamorphic, granitic, and sedimentary rocks in each Core Mountains of the Inner West Carpathians, but showing different orientations between the Core Mountains. These differences may be attributed to young (post-Cretaceous) movements associated with the processes of closing neighbouring flysch basins of the Outer West Carpathians. These deformations propagated into the Inner West Carpathians and re-oriented individual segments and deformed ductilely the Intracarpathian Palaeogene and Neogene.

THE ROLE OF THE TRANS-EUROPEAN SUTURE ZONE IN THE DISTRIBUTION OF VARISCAN AND PRE-VARISCAN PALAEOMAGNETIC POLE POSITIONS

M. Krs, O. Man and P. Pruner (Geological Institute of the Academy of Sciences of the Czech Republic, Rozvojova 135, 165 00 Prague 6 - Lysolaje, Czech Republic)

The work required statistical processing of the Devonian to the Middle Triassic palaeomagnetic pole positions published during approx. last thirty years. The Trans-European Suture Zone (TESZ) is situated at a pronounced palaeolithospheric boundary dividing the Phanerozoic western mobile belts from the East European Craton. The processing clearly showed that the TESZ is not manifest in the distribution of pole positions or palaeomeridian orientations for the Early Permian and younger rocks. However, the blocks of rocks older than the Early Permian and located SW of the TESZ show palaeotectonic rotations of prevalently clockwise sense and of variable rotation values. Extremely high values of rotation are shown by the Early and Middle Carboniferous rocks of the West-European Hercynides, the Middle and Late Devonian limestones from the Moravian Zone, the Devonian and Cambrian rocks of the Barrandian area, Bohemian Massif. Recognition of the role of the TESZ in the distribution of palaeomagnetic pole positions enabled definition of the European APW path during the Variscan Episode. Avoiding the pole positions clearly affected by the palaeotectonic rotation deformations, a relatively smooth path of pole positions without pronounced loops was constructed.

ALPINE AND VARISCAN PALAEOTECTONIC DEFORMATIONS INTERPRETED PALAEOMAGNETICALLY, COMPARISON OF RESULTS FROM THE WESTERN CARPATHIANS AND THE BOHEMIAN MASSIF

M. Krs, O. Man and P. Pruner (Geological Institute of the Academy of Sciences of the Czech Republic, Rozvojova 135, 165 00 Prague 6 - Lysolaje, Czech Republic)

Evaluation of palaeomagnetic data from the Outer Carpathian belt, the Klippen belt and the Inner Carpathians was carried out with the aim to contribute to elaboration of geodynamic models for the Western Carpathians (WC). The data cover the periods from the Permian to the Neogene. The most characteristic features are marked tectonic rotations of the whole rock units, predominantly in an anticlokwise sense. The scatter of pole positions could be explained by a model demonstrating two components of movement, due to continental drift and due to rotation of smaller-scale tectonic blocks during the Alpine collision. In a similar way, as for the WC, the palaeomagnetic data were evaluated for the Bohemian Massif (BM) covering the periods from the Early Cambrian to the Early Permian. Palaeomagnetic data derived from the BM were compared with the coeval data from other European regions north of the Alpine tectonic belt in order to determine some development features of the Hercynian fold belt. Distribution of Variscan and pre-Variscan pole positions indicates large effects of palaeotectonic prevalently clockwise rotations around the vertical axis. The palaeomagnetic data so far derived for the WC and the BM shall be presented with the aim to show similarities and differences in palaeotectonic deformations between the Alpine and Variscan collision zones.

TERTIARY PALEOMAGNETIC RESULTS FROM N. SLOVENIA

E. Márton (Eötvös Loránd Geophysical Institute of Hungary, Paleomagnetic Laboratory; Homonna u. 1, H-1118 Budapest, Hungary)
B. Jelen (Inštitut za Geologijo, Geotehniko in Geofiziko; Dimičeva 14, SLO-1109 Ljubljana, Slovenija)

Paleomagnetic results obtained from 69 sites and localities (nearly 600 samples) will be presented. The ages range from the Eocene through the Pontian. The lithologies are mostly clastic sediments deposited in reductive environment; limestones, tonalites and andesites are subordinate.
The NRMs, carried by magnetite, iron sulphides or both, were thermally demagnetized in increments of 10-100 C°.
More than 80% of the sites and localities yielded well or reasonably well-defined mean directions, all significantly departing from the present Earth field direction at the sampling area. Some of these were proved to be remanences of pre-folding, others of post-folding age. Regardless of the result of the fold test, nearly all site and locality mean directions were interpreted as indicators of past movements.
The distribution in space of the paleomagnetic directions permit to define a broad shear zone, characterized mostly by large (up to 90°) CW rotation, along the Sava and Celje faults as well as the Ljutomer and Ormoz faults. North of it the rotations are moderate in the CCW sense, matching those observed in the Lavantal. and Styrian basins of Austria and the Transdanubian Central Range of Hungary. South of the shear zone the rotations are of Dinaric character, i.e. slight in the clockwise sense. The movements in the shear zone seem to be very young, probably of post-Pannonian age.

PALEOMAGNETIC ROTATIONS IN EASTALPINE TERTIARY BASINS

E. Márton (Eötvös Loránd Geophysical Institute of Hungary, Paleomagnetic Laboratory; Homonna u. 1, H-1118 Budapest, Hungary)
W. Frisch, I. Dunkl, A. Kuhlemann (Institut für Geologie; Sigwartstrasse 10, D-72076 Tübingen, Germany)

Sediments of Ottnangian to Sarmatian (18-12 Ma) age were collected from several intramontane basins of the Eastern Alps at 14 localities. The basins represent pullapart and transtensional structures lined up along the main fault pattern of extrusion tectonics. After the measurements of NRM intensity, susceptibility and the anisotropy of low-field susceptibility in the natural state, the samples were demagnetized in increments, most of them thermally. Low-field susceptibility versus temperature and IRM acquisition behaviour of several samples were studied for the identification of the magnetic minerals. Of the nearly 300 cores drilled in weakly consolidated sediments, about 80% yielded statistically well or reasonably well defined paleomagnetic directions. With a few exceptions all show moderate (25-65°) counterclockwise deviation of magnetic declination from north, both before and after tilt correction. These deviations are interpreted in terms of counterclockwise rotations of domino-like blocks in a regime of eastward flow accelerating from north to south during extrusion tectonics. Although age constraints of the sediments are poor, there appears to be a tendency of larger rotations in the older rocks indicating essentially Middle Miocene rotation. Clockwise rotation in two basins may be related to dextral faulting along the block boundaries.

PALEOMAGNETISM OF THE CENOZOIC EPILIGURIAN CLASTICS FROM THE NORTHERN APENNINES, ITALY

G. Muttoni, Università di Milano, via Mangiagalli 34, 20133 Milano, Italy and L-DEO
N. Abrahamsen, Geophysical Laboratory, Aarhus University, Aarhus, Denmark
A. Argnani, Istituto di Geologia Marina, via Gobetti 101, 40129 Bologna, Italy
I. Cibin, Regione Emilia-Romagna Bologna, Italy
D.V. Kent, Lamont-Doherty Earth Observatory, Palisades NY 10964 USA

Paleomagnetic analysis was carried out at 23 sites from the Cenozoic Epiligurian clastics (northern Apennines). These units were deposited in piggy-back basins located on top of the Ligurian thrust sheets and were affected by limited deformation during tectonic transport. Thus, the Epiligurian units should ideally record the rotational component of deformation of the northern Apennines which is related to the Corsica-Sardinia rotation and Thyrrenian sea opening. All paleomagnetic samples were subjected to stepwise thermal demagnetization. The natural magnetization was measured on a 2G cryogenic magnetometer (Lamont) or a HSM SQUID-based spinner magnetometer (Aarhus). Seven sites of Early/Middle Miocene age yielded dual-polarity site-mean directions which pass the fold test. The overall mean direction gives a paleomagnetic pole (43°N, 282°E) which shows a counterclockwise rotation of 53° with respect to the Miocene paleopole of Africa (or a similar rotation with respect to the coeval Europe reference paleopole). This rotation is of larger magnitude than the post-Oligocene rotation of the Corsica-Sardinia block. The remaining Epiligurian sites bear site-mean directions that fail the fold test and are thus attributed to a recent remagnetization phase. Additional sampling is in progress at new Miocene and Pliocene sites. The overall aim is to obtain a more complete picture of the rotational component of deformation in the northern Apennines.

PALEOMAGNETIC EVIDENCE ON OPENING OF GULF OF SAROS, NW TURKEY

N. Orbay, F. Özcep and M. Hisarlı (Department of Geophysical Engineering, Istanbul University, Avcılar 34850, Istanbul,Turkey)
M. Sanver, C. Tapırdamaz and T. İşseven (Department of Geophysical Engineering, Istanbul Technical University , Maslak 80626, Istanbul Turkey)

Western Anatolia suffered a N-S compressional deformation from the Late Cretaceous till the Miocene. The shortening deformation then gave way to N-S extension which is continuing presently.No rotations have been observed in paleomagnetic field directions obtained Oligocene, Lower Miocene and Plicene rocks collected from Thrace and also Miocene-Pliocene aged rocks collected from Rhodes andCrete islands.These sampling sites are located of Northern and Southern borders of north-south expanding Aegean domain. Miocene field directions obtained from many of the sites all above mentioned areas has an clockwise rotations. Greece and Western Anatolia behaved as a single plate and rotated in clockwise direction till the Upper Miocene times. The average paleomagnetic field directions calculated from Oligocene aged sites which are situated north of Saros Gulf is very similar to the similar aged average direction obtained for Northern Greece. Paleomagnetic field directions obtained from Upper Miocene and Pliocene sites in Thrace have also shown very small rotations. Paleomagnetic field directions obtained from the Gulf of Saros which have ages between the Lower Oligocene and the Upper Miocene exhibit clockwise and anti-clockwise rotations.The collection of new and previously obtained paleomagnetic data from Gulf of Saros and surrounding area is interpreted as an evidence of about thirty degrees of opening of Gulf of Saros since Upper Miocene. This study is supported by TÜBİTAK (Project Nr. YDABÇAG-232-G).

PALEOMAGNETISM FOR THE JURASSIC OF STABLE EUROPE

Settles, E., Soffel, H.C.

To obtain a reliable Jurassic paleopole position for stable Europe, paleomagnetic investigations have been carried out in northern Germany (Weser and Wiehen Mountains, Leine Mountains and the northern border of the Harz Mountains), southern Germany (Franconian and Swabian Jura) and the French Dauphinoise Zone which, relative to Europe, is an autochthonous segment of the Western Alps.
Detailed thermal and AF demagetisation experiments yield good results and multi-component analysis allows the identification of a magnetisation component with higher unblocking temperature spectra (300-500°C). This component passes both fold and reversal tests and is considered primary (jurassic) in origin. A well defined paleopole position for the Upper Jurassic is obtained, helping to constrain the apparent polar wander path for stable Europe. Furthermore, local anticlockwise rotations of approx. 30° can be identified along the northern border of the Harz Mountains. Results from the Dauphinoise Zone demonstrate that this region was rotated to the west, presumably together with the French Western Alps during the Alpine Orogeny.

FIRST PALAEOMAGNETIC RESULTS FROM LOWER DEVONIAN SEDIMENTS OF THE SOUTHERN ALPS AND THEIR PALAEOGEOGRAPHIC IMPLICATIONS

Schätz, M., Tait, J., Bachtadse, V., Soffel, H. (Munich)

The palaeogeographic scenario of the lower palaeozoic terranes of southern Europe is still unclear. The pre-Triassic basement of the Alps was dismembered and dislocated from the Variscan chain of Europe during the break up of Pangaea and the convergence between the European plate and the Adriatic spur of the African plate. In order to determine the pre-Triassic configuration and palaeogeographic affinities of the Carnic Alps, a palaeomagnetic study of lower Devonian sediments has been carried out. Samples were collected in a biostratigraphically well dated sequence of the Carnic Alps: from the Rauchkofel limestone, a crinoid-deposit-limestone with interbedded black, bituminous limestone (Lochkovian), and light grey orthoceras-flaser limestone (upper Lochkovian). The site mean directions pass the fold test, and implies a position adjacent to the northern margin of Gondwana for lower Devonian times. The results also indicate complex rotations related to the motion of the Adriatic microplate in post-Triassic times.

NEW PALEOMAGNETIC RESULTS FROM MIOCENE SEDIMENTS IN THE STYRIAN BASIN (AUSTRIA)

R. Scholger (Institut fuer Geophysik, Montanuniversitaet Leoben, Palaeomagnetiklabor, Gams 45, 8130 Frohnleiten, Austria)
H.J. Mauritsch (Institut fuer Geophysik, Montanuniversitaet Leoben, Franz-Josefs-Str.18, 8700 Leoben, Austria)

The Neogene Styrian Basin, situated at the eastern margin of the Alps, is part of the Pannonian Basin system. In the frame of a multidisciplinary study of the West-Styrian brown coal district, we collected 850 samples from outcrops and also from drill-cores for paleomagnetic analyses. The magnetization of most of the samples was dominated by a viscose component, which goes along with the presence of siderite and goethite in the sediments, as demonstrated by X-ray analysis. The remaining samples, characterized by magnetite- and haematite-components, yielded a paleomagnetic direction, which provides evidence for a 20 counterclockwise rotation of the basin with respect to present North direction. This result is similar to results from Miocene volcanic rocks from the Styrian basin. By means of correlation with biostratigraphy, the section was assigned to chrons C5Dn and C5Dr within the Ottnangian, which leads to an age determination of 17,28-18,28 Ma for the coal and the overlying sediments under investigation.

MAGNETOSTRATIGRAPHY OF PERMIAN - TRIASSIC BOUNDARY SECTIONS IN THE SOUTHERN ALPS IN ITALY

R. Scholger (Institut fuer Geophysik, Montanuniversitaet Leoben, Palaeomagnetiklabor, Gams 45, 8130 Frohnleiten, Austria)
H.J. Mauritsch (Institut fuer Geophysik, Montanuniversitaet Leoben, Franz-Josefs-Str.18, 8700 Leoben, Austria)
R. Brandner (Institut fuer Geologie und Palaeontologie, Universitaet Innsbruck, Innrain 52, 6020 Innsbruck, Austria)

We investigated several Permian-Triassic sections in Southern Tyrol by means of a combination of bio-, litho- and magnetostratigraphy. Strong variations of both the intensity and stability of the magnetization of the samples reflect different sedimentary environments. Magnetite is the dominant magnetic component in most of the samples, while the presence of haematite is characteristic for the immediate Permian - Triassic boundary layer (Tesero horizon). A comparison of the sections near Pufels (Bulla) and Seis (Siusi) provided a magnetostratigraphy from the Bellerophon member (uppermost Permian) unto the Campil member (uppermost Induan).

PALEOMAGNETISM AND EVOLUTION OF OPHIOLITES OF THE NORTHERN URALS

I.A.Svyazhina, G.A.Petrov*, Z.S.Mezenina, R.A.Kopteva (Institute of Geophysics, Urals branch of the Russian Academy, Amundsenstr. 100, Ekaterinburg, 620016, *the Urals geological survey party, Vainerstr, 55, Ekaterinburg, 620145; Russia)

Sections of sheeted dike complex and ryolite-basaltic formation of the Shemur volcanic structure of the Northern Urals were studied. Received ancient components J_n of ophiolites testify to their multi-stage formation. The first stage: the formation of a complex of weak magnetic parallel diabase dikes and pouring of pyritiferous effusives into O_3. Paleomagnetic directions of dikes, bound with hematites are the following - $D=310^0$, $I=-4^0$; the same of ryolites according to magnetite - $D=325^0$, $I=7^0$ and according to hematites - $D=306^0$, $I=5^0$. The second stage: the intrusion of dikes of strong-magnetic diabases and pouring of postmineral basalts into S_1. Paleomagnetic directions of diabases due to magnetite are the following - $D=62^0$, $I=58^0$; the same due to hematite - $D=80^0$, $I=62^0$; the same of basalts due to hematite - $D=80^0$, $I=40^0$ and the same due to magnetite - $D=344^0$, $I=14^0$.The latter corresponds to the magnetization S_1, but the rest were very likely magnetized by the field S_2-D_1 of the time of intrusion of island arc plutons and of late-Caledonian metamorphism of ophiolites (the third stage). The fourth stage: dislocation metamorphism, bound up with the collision C_3-P_1. The late-Paleozoic component is characterized by $D=230^0$, $I=-30^0$ for strong-magnetic diabases and by $D=237^0$, $I=-32^0$ for the rocks of ryolite-basaltic formation Paleomagnetic latitudes, calculated according to ophiolites of the Shemur structure, make up from $3,5^0$ South to 2^0 North for O_3,and 7^0 South - for S_1.

LOWER PALAEOZOIC PALAEOGEOGRAPHY OF ARMORICA: PALAEOMAGNETIC RESULTS FROM THE ARMORICAN MASSIF

Tait,J, Bachtadse, V., Soffel, H: Institut für Geophysik, Ludwig-Maximilians-Universität München.

The palaeo-drift history for the Armorican Massif remains enigmatic for lower Palaeozoic times. Palaeomagnetic data provide conflicting scenarios and it is not clear whether the Armorican microplate (Bohemian, Armorican and Iberian Massifs) formed a coherent tectonic element in Ordovician to Devonian times, or if it represents a tectonic collage of terranes or microplates. In order to help resolve this problem a palaeomagnetic study of upper Ordovician and lower Devonian sediments and volcanics from the Armorican Massif has been carried out. Whilst the Ordovician age rocks are dominated by a remagnetisation of Permo-Carboniferous age, lowermost Devonian limestones yield more reliable results. Thermal and AF demagnetisation experiments reveal a presumed primary component of magnetisation, generally after removal of a present day overprint. Combining stable endpoint and great circle data, this magnetisation direction is identified with mixed polarity, and yields an overall mean direction of 221°/34° (11 sites) after bedding correction. This corresponds to a palaeolatitude of 20°S for the Armorican Massif, placing it in its present day orientation, and adjacent to the southern margin of Baltica and Avalonia. These results will be compared with Siluro-Devonian results from elsewhere in central Europe, and the implications for the palaeogeography and geodynamic evolution of Variscan Europe will be discussed.

SE15 Rock- and palaeomagnetism and environmental magnetism

Convener: Hoffmann, V.

04 Magnetic properties of minerals and rocks

Convener: Dunlop, D.J.
Co-Conveners: Dekkers, M.J.; Hoffmann, V.

A PALAEOMAGNETIC STUDY OF DEVONIAN AGE SEDIMENTS FROM THE EASTERN PYRENEES, SPAIN.

Tait,J, Bachtadse, V., Institut für Geophysik, Ludwig-Maximilians-Universität München: Parés, J-M., CSIS, Barcelona: Dinares, J., Fort Hoofddijk, Utrecht.

In order to constrain the Devonian palaeogeography of palaeozoic terranes now incorporated within the Alpine fold belt, a detailed study of sediments from the eastern Pyrenees has been carried out. Samples were collected from biostratigraphically well-dated, relatively undeformed limestones from three distinct localities within the Axial Zone, and subjected to detailed thermal and AF demagnetisation experiments. Results show a high unblocking temperature component of magnetisation with fairly steep (approx 60°) inclination values. Directions pass the fold test within site, and between site for the different localities. Significant variations in declination values between the localities may be interpreted as differential rotation of the different units during the Alpine or Hercynia orogenies. If this magnetisation is considered primary in origin, then it implies a major oceanic separation between this palaeozoic terrane and the rest of Europe (ie the Iberian, Armorican and Bohemian Massifs) in lower and mid Devonian times.

A STRUCTURAL AND PALOMAGNETIC LOOK AT THE CANTABRIA ARC, NORTHERN SPAIN

A.B. Weil and R. Van der Voo (Department of Geological Sciences, University of Michigan, Ann Arbor, MI 48109, U.S.A.)
J.M. Pares (CSIC Insitut de la Terra Jaume Almera, Barcelona, Spain)

A detailed paleomagnetic study was carried out on Devonian limestones in four complex structures of the Cantabrian Arc, Northern Spain. This Variscan Arc comprises a foreland thrust belt, which is unique in that it exhibits almost 180 degrees of curvature concave towards the foreland. We have thus far found two distinct syntectonic magnetizations; an Early Permian (B) component with shallow inclinations that postdates Stephanian (F1) folding, and a Late Carboniferous (C) component that is synfolding. In three of the four structures, and in the arc as a whole, a significant amount of vertical axis rotation is recognized which postdate both B and C magnetizations. In two of the locations, the Lagos Del Valle and the La Queta synclines, we observe localized F2 tilting about east-west horizontal axes that postdates the (B) component and the F1 folding about north-south horizontal axes. In the Proza Anticline and Lagos Del Valle syncline, a consistent relationship between the declinations and the bedding strike is observed, but in the southerly East-West structure such a correlation seems absent. The spatial distribution of magnetizations and their ages suggests that Variscan deformation has been multiphase and protracted, continuing into the Permian.

Coercivity of heterogeneous interacting particles assembly

L. L. Afremov and A. V. Panov (Far-Eastern State University, 8, Sukhanova, Vladivostok, 690600, Russia)

Influence of magnetostatic interaction on the remanence of saturation I_{rs} and coercivity H_c of an assembly of heterogeneous grains of titanomagnetite is investigated. The research is conducted within the framework of model of two-phase particles having shape of parallelepiped and consisting of two uniformly magnetized phases with different spontaneous magnetizations and anisotropy constants. The method of random field is used in the evaluation of magnetostatic interaction in an assembly. Calculations show that the interaction has chaotic effect on distribution of magnetic moments of particles. It results in reduction in magnitude of remanent magnetization of saturation I_{rs} and coercivity H_c in comparison with an assembly of non-interacting grains. And H_c of heterogeneous grains assembly varies most considerably because its relaxation times are less relaxation time of chemically homogeneous particles.

Self-reversal of TRM on dacitic pumices from the 1991 Pinatubo eruption (Philippines): new data

M. Bina, J. C. Tanguy (Laboratoire de Géomagnétisme, Univ. Paris 6, CNRS, 94107 St. Maur, France)
V. Hoffmann, R. Keller (Institut für Allgemeine und Angewandte Geophysik, Univ. München, Germany)
M. Prevot, A. Goguitchaichivili (Laboratoire de Géophysique et Tectonique, Univ. Montpellier II, France)
K. Th. Fehr (Inst. of Mineralogy, Petrology, Geochemistry, Univ. München, Germany)
E. L., Listanco, R. S. Punongbayan (Philippine Institute of Vulcanology and Seismology, Quezon City, Philippines)

The NRM of about 40 samples collected from several sites on the Pinatubo ignimbrite field shows self-reversed magnetisation. An iron-rich Al and Mg substituted titanomagnetite (x≈0,1) and hemoilmenite with little Al and Mg substitution (y≈0,5) were found to dominate the magnetic properties of these rocks. Here we focus on results of our new studies with the aim of characterizing more precisely the at least 2 different hemoilmenite phases being responsible for the self-reversed TRM: (i) Low- and high-temperature susceptibility using KLY3, (ii) microchemical and micromagnetic analyses performed on the same particles and (iii) additional TRM-experiments. In conclusion, the SR-TRM could be due to chemically zoned hemolimenite particles (core and rim phase) and strong magnetic interaction (coupling) between these phases.

PHYSICAL PROPERTIES OF PURE AND SUBSTITUTED MAGNETITE SYNTHETIC SINGLE CRYSTALS

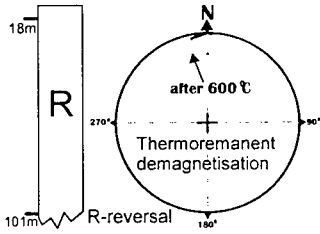
V.A.M. Brabers (Department of Physics, Eindhoven University of Technology, P.O. Box 513, NL-5600 MB Eindhoven, The Netherlands)

Magnetite is the most abundant ore component responsible for the magnetic properties of magnetic rocks. However, in most magnetic minerals, the magnetic phase is not the pure Fe_3O_4 compound, but contains usually a number of impurities like Mg, Al, Ti... and deviations from the ideal oxygen stoichiometry are also frequently found. In this paper the effects of the chemical composition upon some specific physical properties will be reported. To study these effects, synthetic single crystals were prepared by a floating zone technique, which enabled us to produce high-purity as well as intentionally substituted magnetite crystals. For spectroscopic pure crystals, the Verwey transition took place at 125 K but was found to be lowered drastically by impurities. The magnetostriction constants as well as the magnetic anisotropy, which are decisive parameters in the study of magnetic domain structures, are strongly affected by the presence of anisotropic ions like Co^{2+} and Fe^{2+}, which will be shown by the composition dependence of these properties. High field magnetization measurements up to 36 Tesla on the titanomagnetite series $Fe_{3-x}Ti_xO_4$, revealed that for high Ti-concentration a magnetic spin glas structure occurs, in contrast to the Néél antiparallel ordering scheme or the spin canting at lower Ti-concentration.

RESULTS OF PALEOMAGNETIC INVESTIGATIONS OF BORE HOLE B4 FROM ZLOT GEOMAGNETIC ANOMALY (SERBIA)

Aleksandar Djordjevic[1], docent; **Natasa Mekic**[1],teaching assistant; Miroslav Starcevic[1],associate professor; Dragan Milovanovic[1], full professor and Vlado Milicevic[2], Ph.D

-Locality: Zlot geomagnetic anomaly-SW (30km) from Bor (the biggest cooper deposit in Yugoslavia)
-Intensity of anomaly field of Z-component are from (-25000 nT) to 45000 nT.
-Well B4 are in the anomaly field of Z-component from (-25000 nT).



-Relatively age of locality: Upper Cretaceous?
-Paleoinclination are -28°
-Absolut age of rocks and minerals will be determinate.
-NRM=(from 366 nT to 295900 nT)
-Intensity of RM after demagnetization: (from 2000nT to 104000nT)

Volcanic rock: Andesites composed of intermediate plagioclase, clinopyroxenes wich lie in glassy ground mass.
Specific mineral is spinelle (up to 25% volume of rocks)

NATIVE IRON IN BAKED SEDIMENTS DUE TO SPONTANEOUS UNDERGROUND COMBUSTION OF COAL SEAMS

C.B. de Boer[1], A.A.M. van Hoof[1], Z. Xiangmin[2], S.B. Kroonenberg[3], M.J. Dekkers[1] (1) Paleomagnetic Laboratory 'Fort Hoofddijk', Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands. (2) Department of Earth Resources Surveys, ITC, P.O. Box 6, 7500 AA Enschede, Netherlands. (3) Faculty of Technical Earth Sciences, Mijnbouwstraat 120, 2628 RX Delft, Netherlands.

In China, spontaneous underground combustion of coal is a serious economic and environmental problem because of the loss of coal (20-200 million tons per year) and the corresponding CO_2 release (2-3% of the global annual CO_2 output). Thermomagnetic analysis clearly indicates native iron (T_C = 770°C) in baked and molten rocks adjacent to burnt coal seams in northwest China (Pleistocene and Holocene combustion). Magnetite, maghemite and hematite also occur. The iron is surprisingly stable because it survives heating in air to 300°C in the Curie balance, presumably because it is contained in a shell of much more stable magnetite which in turn can be rimmed with hematite. The occurrence of strongly magnetic native iron, magnetite and maghemite in the baked rocks offers potential for the delineation of the areal extent of the combustion with magnetic anomaly methodology.

PALEOINTENSITY AND ROCK-MAGNETIC EXPERIMENTS ON HISTORIC LAVA FLOWS FROM MT. ETNA.

M. Calvo (Dep. Física de la Tierra I, Universidad Complutense, 28040 Madrid, Spain)
M. Prévot and M. Perrin (Lab. Géophysique et Tectonique, Univ. Montpellier II, France
M. Borreguero (C.P.J.L., Fuenlabrada, Madrid, Spain)

Paleointensity experiments were carried out on 28 selected samples belonging to six basaltic lava flows from 1910 and 1928 from Mt. Etna (Sicily, Italy). Intensities obtained from the experiments can be compared to the known field intensity at the time the lavas cooled. The aim of these studies was to obtain information about the effect of mineralogical/chemical alterations and the presence of multidomain grains on paleointensity determination. For paleointensity experiments, each of the samples was cut into two halves -a main sample and a control sample- and subjected to three heating/cooling runs at each temperature step up to 590°C. At certain temperature steps and at the end of the experiment multiple pTRM checks were carried out. Rockmagnetic studies including measurement of susceptibility versus temperature curves, vibrating sample magnetometer experiments, hysteresis curves, isothermal remanence acquisition curves and determination of viscosity indexes were performed on samples from all six flows in order to determine their magnetic mineralogy and to asses their suitability for paleointensity studies.
Results obtained in these experiments are reported.

"SWIRLS" OF MAGNETIZATION IN PSD MAGNETITE

K. Fabian (Department of Physics University of Toronto, Erindale Campus Mississauga, Ontario Canada, L5L 1C6 and Institut für Allg. u. Angew. Geophysik, Theresienstr.41/IV, 80333 München, Germany)

Three-dimensional models of magnetization structures in PSD magnetite show distinct magnetization swirls which propagate all through the particle. By means of different mathematical methods it is possible to distinguish between several types of magnetization swirls, which include the well-known vortex structures as well as "antivortex" structures. It is shown, that the swirl diameter in vortex structures varies with the distance from the surface. The central diameters increase linearly with the grain dimension, while the surface diameter is nearly independent of the particle size. There is a variety of structures with two distinct magnetization swirls. They occur as metastable magnetization states when minimizing a homogeneously magnetized initial state. While the magnetic moment of single vortex states is carried by the vortex itself, the moment of double vortex states is carried by a central domain. The structural differences of single domain, vortex and double vortex states influence the nucleation behaviour with respect to the nucleation process (e.g. TRM, CRM or ARM). Especially the single vortex nucleation may be inhibited during TRM acquisition, giving rise to extremely high M_{TRM}/M_{ARM} ratios in PSD magnetite.

UMERICAL MODELLING OF SUSCEPTIBILITY IN FERROMAGNETIC OCKS : THE ROLE OF MAGNETIC INTERACTIONS

. Gaillot, V. Grégoire and M. de Saint Blanquat (UMR 5563 -CNRS-8 rue des 36 ponts F-31400 Toulouse)

he part of non-uniform spatial distribution in the Anisotropy of lagnetic Susceptibility (AMS) of rocks has been recently investigated. he theoretical studies have shown that when magnetic interaction etween neighbouring grains is present, the AMS results more from iis interaction rather than by single-grain shape anisotropy.
)n the basis of the former theoretical works, we present a 3D numerical iodel, in which each individual grain has its own magnetic anisotropy, olume and orientation. Preliminary results for two grains in various patial configurations, fit well with the experimental data of Grégoire et l. (1995).

régoire, V., de Saint Blanquat, M., Nédélec, A., and Bouchez, J.L., 1995, hape anisotropy versus magnetic interactions of magnetite grains : xperiments and application to AMS in granitic rocks. Geophys. Res. ett., vol. 22, 20, 2765-2768.

PECULIARITIES OF MAGNETIC MINERALS FROM MASSIVE SULFIDE DEPOSIT. (139 CRUISE ODP, HOLES 856G,H)

T.S.Gendler, D.M.Pechersky, Z.V. Sharonova, E.A.Chaliulina (UIPE RAN Gruzinskaja 10, 123810 Moscow, Russia) , S.G.Krasnov (Institute of Geology and mineral resources of Ocean, St.Peterburg), L.E.Sholpo (S-P IZMIR RAN, St.Peterburg)

Black Smoker is ideal natural laboratory for the study of Fe-S minerals formation. Samples from massive sulfide deposit about 80 m of high (.Endeavour Segment Juan de Fuca Ridge) were studied using complex rock magnetic methods, X-ray and Mossbauer spectroscopy (MS). It was shown the samples have a heterogeneous texture and content mainly Fe-sulfides and magnetite. Variations of their proportions determined from MS analysis and Is and Ist/Is values along the cores made it possible to subdivide this deposit into 4 zones with different levels of mineral alterations. Predominant minerals are pyrite, markasite and pyrrhotites both monoclinic (Pym) and hexagonal (Pyh). Pym from different zones demonstrated different thermal stability and different Tc(Tb): 320 and 340-360 oC . After first heating unusually high Tc and Tb ~360-370 oC were observed for all the samples. Pyh also showed different thermomagnetic behavior : usual pronounced I-peak at 250-270 oC, smoothing peak (plato) in the same temperature interval, un-peak curves with Tc(Tb) in the range 100-260 oC. Computer fitting of pyrrhotites MS showed the reason of unusual Tc,Tb is the iron vacancies disordering of Pym and partly vacancies ordering of Pyh. Magnetite was the major mineral of one of sulfide depozit zone. It demonstrated unusual low Tc,Tb: 520-560 oC. Low Tc were observed also for magnetite formed after heating of the pyrite containing samples. All these peculiarities reflect the multistage process of hydrothermal sulfide crystallization and consequence alteration . The intermediate metastable phases are formed as a result. The remanent coercive spectra study (test L.Sholpo) and comparing of NRM and ARM values (test Pechersky-Nguen) made it possible to recognize magnetite NRM as crystallization one and to estimate the temperatures of Pym and magnetite formation (Tf ~350 oC).

MODELING OF THE FERRIMAGNETIC CRYSTALLISATION PROCESS UNDER VARIOUS P-T-pO_2 CONDITION

Yuruj Genshaft, Vladimir Tselmovitch, and Anatolij Gapeyev (Geophysical Observatory "Borok", Nekouzskij region, Yaroslavskaja oblast 152742, Russia)

The problem of formation and existence of ferrimagnetics during of crystallisation of magmatic melts still open the question. The authors simulated deep crystallisation of ferrimagnetics from basaltic melts under various P-T-pO_2 conditions. The experiments were carried out at pressure 20 kbar in a range of temperatures 1150-1350 °C with basalt's from Island with addition of ilmenite and K2CO3. The experiments have shown, that in the initial basalt at pressure 20 kbar ferrimagnetcs do not form. After takes place addition of picroilmenite olivin and ilmenite crystallise, ilmenite contains more than 10 w. % MgO. The grains of ilmenite, formed in an interval of temperatures 1200-1150 °C do not contain hematite in a solid solution. The experiments with the additives of K_2CO_3 have shown a sharp narrowing of a field of crystallisation of ilmenite and a rather wide field of titanomagnetite formation . Under more oxidising conditions of crystallisation new illuminate contains less MgO. In the experiment lasted about 1 hour the replacement of initial ilmenite to titanomagnetite, and the formation of sphene and titanflogopite is observed. Measurements spontaneous magnetisation of the samples have shown, that in more oxidising conditions leads to increase of magnetisation.

THE INTERACTION BETWEEN MAGNETIC AND CATION ORDERING

Richard J. Harrison and Andrew Putnis

Institut für Mineralogie, Universität Münster, 48149 Münster, GERMANY.

It is often assumed that the magnetic properties of Fe-bearing spinel solid solutions are much more sensitive to the total concentration of Fe in the mineral than they are to the partitioning of Fe between tetrahedral and octahedral sites. Recent experiments on magnesioferrite and the magnetite-spinel solid solution challenge this assumption. In both these systems the Curie temperature is shown to be strongly influenced by the temperature-dependent partitioning of Fe between sites, with a difference in T_c of up to 100 °C between the most ordered and disordered samples studied. The magnitude of this effect is significantly underestimated by current theoretical models, and a new thermodynamic approach to the problem is discussed. The free energy associated with both magnetic and cation ordering is described by polynomial functions of the magnetic and cation order parameters, Qm and Q respectively. Coupling between the two processes is described by an additional term of the form λQQm, where λ is constant for a given composition. In cases where the kinetics of cation ordering are very slow, the model predicts a linear variation in the Curie temperature as a function of the degree of cation order. This is confirmed experimentally for magnesioferrite. In cases where the kinetics of magnetic and cation ordering are similar (e.g. in magnetite), the model predicts that the degree of cation order is significantly enhanced below the Curie temperature. The possible consequences of this effect for natural magnetic minerals are discussed.

agnetic properties and paleointensity from Southwest Icelandic lcanic rocks recording the "R_3 - N_3" magnetic polarity reversal

T. Goguitchaichvili and M. Prévot (Laboratoire de Tectonique et eophysique, Univ., Montpellier 2, 34095 FRANCE)

ost paleointensity studies indicates a reduction of the virtual dipole oment (VDM) reduction during geomagnetic reversals. In contrast law et al. (1975) reported the occurrence of a relatively large VDM ring part of the R_3 - N_3 reversal. We resampled in detail most of the quences and flows studied by Shaw (56 lava flows and 2 baked dimentary layers). Most of the intermediate lava flow show a quite g capacity for acquiring a viscous remanent magnetization (viscosity dex is more than 10% and sometime exceed to 50%). Most of the ermomagnetic curves (induced magnetization and susceptibility vs. mperature in vacuum) show an irreversible behaviour and at least the esence of two magnetic phases. Experiments carried out using a brating sample thermomagnetometer show that in general partial ermoremanent magnetization acquired between 300°C and room mperature is only completely destroyed near 600°C. This behaviour typical of multidomain grains which are generally unsuitable for leointensity.

THE INFLUENCE OF PRESSURE ON THE ACQUIRING OF THERMOREMANENT MAGNETIZATION

N. A. Hasanov and **V. I. Maksimochkin** (Address: Bashkir State University, Frunze str., 32, Ufa, 450074, Russia)

The existing theories do not give a satisfactory quantitative explanation for the influence of pressure on the magnitude of the thermoremanent magnetization (TRM) of an assemblage of two-domain grains. A new calculation of the influence is proposed based on a modified Schmidt model of the creation of TRM. Particularly, the following formula was obtained for the magnetite TRM acquired and measured under the pressure -σ parallel to the field H (where H is in Rayleigh range):

$$I_{rT} = 2I_s(T)SN\left(\frac{q\Pi^{1/(p-1)}}{2D}\left(\frac{AH}{p-2}\right)^{(p-2)/(p-1)}(F_0 + F_1R) - (G_0 + G_1R)\nu\right)$$

where $R = 3\sigma\lambda_{111}/(2K_1)$, S is the grain cross-sectional area, N is the concentration of grains, ν is the average distance between the barriers which was changed when the pressure was applied. The values of F_0, F_1, G_0, G_1 depend on p and the type of anisotropy only. The formula shows that the TRM acquired and measured under pressure is smaller than the TRM acquired under normal conditions if $\lambda_{111} > 0$. There is an agreement between experiments and our calculations.

NON-LINEAR MAGNETIZATION IN HEMATITE BASAL PLANE AND ITS IMPLICATION FOR AMS DETERMINATION

F. Hrouda (AGICO Inc., Box 62, CZ-612 46 Brno, Czech Republic)
H. Quade (Geol. Inst. TU, Leibnitzstr. 10, D-38 678 Clausthal-Zellerfeld, B.R.D.)

Hematite single crystals from Belo Horizonte (Brazil) show their low-field susceptibility to be field independent along the c-axis and strongly field dependent in the basal plane (3 times higher in the field of 2.4 microT than in the field of 0.24 microT). This susceptibility no longer corresponds to the initial susceptibility. Using common fields (several microT) and linear fit in constructing susceptibility tensor fails. AMS measurement in very weak field can solve the problem.

GYROMAGNETIC REMANENCE ACQUIRED BY PYRRHOTITE DURING STATIC THREE-AXIS AF DEMAGNETIZATION

S. Hu and E. Appel (Institut fur Geologie und Paläontologie, Universität Tübingen, Sigwartstr. 10, 72076 Tübingen, Germany)
S. Wang (Nanjing Institute of Geography and Limnology, 73 East Beijing Road, Nanjing 210008, China)

Gyromagnetic remanence (GRM) acquisition is observed in about 20% of a large number of lacustrine sediments from the Tibetan Plateau during static three-axis alternating field (AF) demagnetization. Detailed magnetic investigations were made. Magnetite and hematite are detected. However, another magnetic component, unblocked around 350°C, proves to be the dominant magnetic mineral and the GRM carrier. Most likely this component is pyrrhotite. GRM intensities are mostly in the same order as NRM, while some samples show much stronger GRM although their magnetic properties are similar. With x being the last demagnetization direction, GRM in high fields is generally acquired along the y axis. Variation of the demagnetization sequence confirms that GRM is always produced perpendicular to the AF direction. Anisotropy direction is derived from GRM, however, systematic studies on pyrrhotite are needed for detailed conclusions. Attempt of GRM correction failed due to high GRM intensities, and because smaller GRM acquisition is found also along the demagnetization axis. Behaviours of acquisition and AF demagnetization of GRM are comparable with those of NRM, ARM, IRM, indicating quite homogeneous grain sizes of remanence carriers.

THE RESOLUTION OF CURVES TEMPERATURE DEPENDENCE SPONTANEOUS MAGNETIZATION OF MULTIPHASE FERRIMAGNETIC FRACTION OF ROCKS INTO ITS COMPONENTS

Sh.Z.Ibragimov, P.G.Jasonov, I.G.Denisov, D.K.Nurgaliev
(Faculty of Geology, Kazan University, 420008, Kazan, RUSSIA)

The method of the resolution of curves temperature dependence spontaneous magnetization (Is(T)) rocks samples, containing few ferrimagnetic phases, have been proposed. The base of the method is addition of the spontaneous magnetization of these phases. The dependence describing few experimental types Is(T) of ferrimagnetics have been proposed. The method was examineted on samples with known composition of ferrimagnetics. The conclusion about of possibility of use the method for quantitative analyse of a multiphases ferrimagnetic fraction of rocks have been made.

DEPENDENCE OF MS AND ORIENTATION OF AMS FROM SUCCESIVE HEATS: A NEW METHOD OF DETERMINATION LATENT TECTONIC STRESSES

A.P.Ivakhnenko, A.V.Sukhorada, N.I.Guzij, S.A.Popov (Kiev University, Geological Dept.,Geophysic, Vasilkovskaya Str. 90, Kiev, 252022, UKRAINE, e-mail: iap@rpd.univ.kiev.ua)

We present a new method of determination latent and late orientations tectonic stress on the basis of a study MS and orientation AMS attached to succesive heats. Precambrian crystalline rocks three geological stages of Gaysin block have been investigated.The firstreductive stage is presented by pyrrhotiniferous enderbite 1 with horizontal strike direction AMS (A). The second oxidizing stage is offered by diorite (A 350) and angle of dip to north-east (B 70NE). The third oxidizing stage is also presented by granite (A 305, B 80NE) and changeble pyrite-magnetitiferous enderbite 2 (A 315, B 69NE) of first stage. These rocks were in succession heated to T= 720C into air. After each period of heating AMS and MS was measured. Orientations AMS enderbite 1 (A 305, B 70NE) have coincided with enderbite 2 (A 310, B 68 NE) to T 400C. During subsequent heating to T 720C orientation AMS enderbite 2 has become the same as diorite (A 350, B 70NE). Orientations AMS of diorite and granite were invariable. Probable mechanism of formation record orientations of AMS is adduced.

MAGNETIC MINERALOGY OF BURNT CLAY FROM AN AENEOLITHIC SITE FROM BULGARIA

N. Jordanova, and D. Jordanova, Geophysical Institute, Acad.Bonchev Str., bl.3, 1113 Sofia, Bulgaria

All samples studied are of identical age but they are taken from two different structures of the site. The two groups of samples show different magnetic properties. The first set of samples, taken from a very well preserved oven, showed magnetite as a main ferrimagnetic mineral when $J_{rs}(2T)$ is thermally demagnetized. At the same time continuous thermal demagnetization of NRM reveals the presence of high T_b, characteristic of haematite or maghemite, in addition. AF- and step-wise thermal demagnetization, as well as hysteresis measurements, however, support the presence of magnetically soft minerals. During continuous thermal demagnetization of TRM, acquired in a field of 0.2mT, a reverse component is observed at about 250-300°C. The second set of samples came from a structure that had been rammed before the initial burning of the clay. In that case the main ferrimagnetic mineral carrying a TRM is magnetite. A T_b of ~200°C, connected with a high-coercivity part of J_{rs} is observed also. This magnetic phase does not change during repeated heatings up to 650°C and may be due to the presence of hemoilmenite. The calculation of differential remanence $\Delta M=I_{DC}(H)-(1-2IRM(H))$ points to a positive type of interactions in contrast to all other samples. The possibility for the influence of the strong mechanical treatment on the observed properties will be discussed. A conclusion can be drawn that the mineralogical content of the material used for archaeomagnetic studies can be quite variable

he conditions of formation and evolution of the magmatic rocks y a magnetic diagnostics.

.K. Kakoulia, D.Z. Sologachvili, E.SH. Pavlenichvili and A.T. oguitchaivili (Tbilisi State University, Geophysics department, 3 Av shavtshavadze, 380028 Tbilissi, GEORGIA)

lagmatic rocks with different mineralogical composition and ages ere sampled either in the outcrops or in the borehole. The obtained ıta allow us to conclude that:

Hypergenetical transformations of the effusive rocks can by detected / magnetic parameters only after 0.8 - 1.0 M.a. after their nplacement.

Domain structure of magnetite changes significantly during the /pergenetical transformation. We observed the increase of the ›ercive force and decrease of the magnetic susceptibility. Differential ıermo-magnetic (DTM) curves and Preisach diagram suggest a :esence of single-domain ferrimagnetic phase with strong magnetic teraction which disappears when heated to the 180 - 200 °C.

CHEMICAL MAGNETIZATION OF GROWING INTERACTED ULTRADISPERSED GRAINS ENSEMBLE

P.V.Kharitonsky, A.Yu.Ralin, J.G.Voronina (Dept. of Physics, Far Eastern State University, 8 Sukhanova str., Vladivostok 690600, Russia)

Magnetization curves of the ensemble of superparamagnetic dipole-dipole interacted grains growing in external magnetic field were calculated. The rising of magnetization are caused by two reasons. Firstly, grain volumes increase and, hence, their magnetic moments increase also. Secondaly, parameters of random magnetostatic interaction fields (mean field, dispersion, etc.) change, increasing mean magnetic moment of the grains. Size and concentration of the grains strongly influence the initial parts of magnetisation curves. If the size is less than critical size of superparamagnetizm d_s and concentration is small then magnetization is almost equal to zero in low fields. Rising of external field causes the transition to superparamagnetic state and increasing of magnetization starts. When the grain size is more than critical then growth of magnetization starts even if the field is low and consentration is small.

PYRRHOTITE FROM A 9.1 KM DEEP CRUSTAL PROFILE - MAGNETIC AND MINERALOGICAL DATA

A. Kontny and H. de Wall (Geologisch-Palaeontologisches Institut, Im Neuenheimer Feld 234, D-69120 Heidelberg, Germany)

Pyrrhotite is the most abundant magnetic mineral in the paragneisses and amphibolites of the KTB deep drilling project of Germany which reached in-situ temperatures of about 260B0C. Therefore these rocks offer an unique opportunity to study structural and magnetic phase relations of natural pyrrhotites. Using optical, mineral chemical, TEM and thermomagnetic methods, two types of pyrrhotite were distinguished: 1) monoclinic, ferri-magnetic 4C pyrrhotite with a metal content (Fe+Ni+Co) of 46.04-47.02 at.% and, 2) 'hexagonal', antiferro-magnetic pyrrhotite types (5C, 6C, NC) with a metal content of 47.05-47.6 at.%. The second type predominates below about 8100 m depth (in-situ temperature ca. 220B0C). According to experimental data, ferrimagnetic NA pyrrhotite should be the stable in-situ phase under these conditions. However, we observed ordered low temperature 5C, few 4C and 2C pyrrhotite. Rarely was the NA type recorded, stable at high temperatures, which may be preserved metastably. It is assumed, that all the observed ordered (low temperature) phases formed from this NA phase during the uplift of the samples from the borehole bottom to the surface. Our data suggest, that naturally occurring ferrimagnetic 4C pyrrhotite is not stable above 220B0C and that the ferrimagnetic NA type may have a larger compositional range as previously assumed. This interpretation is in agreement with calculated vacancy ordering models of PF3sfai and DF3dony (1990) 2E PF3sfai, M. and I. DF3dony, Eur. J. Mineral., 2, 525-528, 1990.

CHANGES OF MAGNETIC PARAMETERS OF ROCKS WITH DEPTH BASED ON EXPERIMENTAL THERMOBARIC DATA

T.S.Lebedev, B.Y.Savenko (Inst. of Geophysics, Nat Ac Sci Ukr, Kiev-142, Ukraine 252142)

Experimental PT-data show that the changes of remanent magnetization of eruptive rocks of the Ukrainian Shield (USh) with depth occur within a wide range depending on their types and thermodynamic formation conditions. Most significant changes of the remanent magnetizations are characteristic of the upper crust (to ca. 8 km depth) and deeper the remanent magnetization is only decreased by temperature. Also studied was depth distribution of magnetic susceptibility and P and T effect. The contribution of these factors has been estimated for different depths. The role of the remanent in total magnetization is significant in the near-surface layers. Within the USh, the total magnetization value can be notably influenced by only ultrabasic (and partly basic) rocks.

PT-DEPENDENCES OF MAGNETIC PARAMETERS OF MAGNETITE

T.S.Lebedev, B.Y.Savenko (Inst. of Geophysics, Nat Ac Sci Ukr, Kiev-142, Ukraine 252142)

Studies of magnetization of natural crystals of magnetite (Mgt) of different genesis from some rocks of upper crustal horisons of the Ukraine territory have been made. Pressure stability (to 300 MPa) of their natural remanent magnetization (In) and remanent saturation magnetization (Irs) is different (the highest one for crystals of magmatic, the lowest one for those of metasomatic and the intermediate one for those of other genesis). The same picture is preserved at simultaneous P (to 300 MPa) and T (to 300 C) effect. For magmatic Mgt the role of T in demagnetization is predominant. A significant P effect on demagnetization of Mgt of metamorphic or volcanic-sedimentary genesis is only seen in the initial P and T range.

UNUSUAL LOW-TEMPERATURE SUSCEPTIBILITY BEHAVIOUR OF AN ASH FLOW FROM THE NEVADO DE TOLUCA VOLCANO, MEXICO.

Gregg McIntosh, H. Böhnel & J.L. Macias, Instituto de Geofisica, UNAM, México.

The variation of magnetic susceptibility between liquid nitrogen and room temperature provides a means of identifying multidomain Ti poor titanomagnetites; at -150 °C susceptibility shows a characteristic peak. Samples from a 20-30 kyr ash flow from the Nevado de Toluca volcano, México were subjected to such experiments as part of a study into their magnetic properties. Whilst they indeed showed a pronounced peak, it occurred at a temperature of -100 °C. Such temperatures were reproducible irrespective of sample preparation; furthermore a 'multidomain' peak was observed at -150 °C for a basalt sample run as a calibration test, precluding anomalous thermal hysteresis between the sample and thermocouple as an explanation. Curie temperatures of between 350 and 520 °C for these samples testify to deviation from pure magnetite composition. Increasing Ti content decreases Curie temperature but suppresses the susceptibility peak. Whole rock chemical analyses of the ash flows indicate a high Al content. Al substitution would also reduce Curie temperatures. One possibility is that it also increases the temperature of the susceptibility peak.

WASP-WAISTED HYSTERESIS LOOPS IN MEXICAN IGNEOUS ROCKS.

Gregg McIntosh & Harald Böhnel, Instituto de Geofisica, UNAM, Mexico.

Wasp-waisted hysteresis loops result from a magnetic mineral population exhibiting discrete coercivity fractions and they have been commonly observed in remagnetised carbonate rocks. Here we report the occurrence of wasp-waisted loops in a suite of Mexican igneous rocks, both intrusive and extrusive. The different rocks exhibit loops of varying shapes, reflecting differences in the magnetic mineral distributions. Such differences are expressed in the values of the determined hysteresis parameters. For example, an early Tertiary/late Cretaceous intrusive rock yielded an Hcr/Hc ratio of *ca.* 10, as would be expected for a mixture of high and low coercivity minerals, whereas a Quaternary lava had a corresponding value of *ca.* 1. High Hcr/Hc ratios, therefore, are not a feature of all mineral assemblages that produce wasp-waistedness. Further characterisation of the mineralogy, via thermomagnetic measurements and detailed remanence acquisition, has been carried out to discriminate between the different mineral populations present in the various rocks and assess their contribution to the overall magnetic properties.

CHARACTERIZATION AND MAGNETIC PROPERTIES OF GOETHITES SYNTHETISED IN THE PRESENCE OF DIAMAGNETIC ELEMENTS

P.-E.Mathé, P.Rochette, Y.Noack (CEREGE, Arbois BP80, 13545 Aix-en-Provence Cedex 04, France); A. Decarreau (Laboratoire Pétrologie de la Surface- URA 721, 86022 Poitiers Cedex, France)

A set of goethites with varying gallium content have been synthetized, and characterized using X-Ray diffraction, InfraRed spectrometry, Mössbauer at room temperature, XANES and EXAFS spectroscopies. Results indicate a solid solution between $\alpha FeO(OH)$ and $\alpha Fe_{0,6}Ga_{0,4}O(OH)$, with no evidence of preferential octahedral sites substitution for Ga.
Magnetic properties of samples have been investigated as well. Ordering temperatures fall and spontaneous magnetizations are enhanced with increasing substitutions of diamagnetic elements. However, saturation remanence at 0K gives similar values than pure goethite (0,1-0,4 Am^2/kg), suggesting that parasitic moment in goethites is not directly due to substitution, but linked with defects, such as vacancies, extra structural water or electrons.
It is also shown that thermomagnetic curves using low-field susceptibility are suitable to characterize goethites and determine their amount of diamagnetic defects with their Néel temperature.
Thermochemical transformations have also been investigated. They leads to high susceptibility phases. The initial substitution degree of goethites influence the kinetics of transformation and ordering temperatures of neoformed minerals.

A POSSIBLE MECHANISM FOR SELF-REVERSING MAGNETIZATION OF INHOMOGENEOUS FERRIMAGNETIC GRAINS

A.N. Nekrasov (Institute of Experimental Mineralogy, Russian Academy of Sciences, Chernogolovka, Moscow district, 142432 Russia)

The occurrence of inhomogeneous ferrimagnetic grains (IFGs) in a nonsingle-domain (NSD) state is a necessary condition for their partial or total self-reversing magnetization (SRM). In such a state, IFG zones with the higher Curie temperature are primarily magnetized opposite to the magnetic moment sense of IFGs in a single-domain (SD) state, as shown before (Nekrasov, 1996). Changes in the environmental conditions or physico-chemical structure alter the IFG domain structure; as a consequence, the total magnetic moment and the degree of SRM development also change. The major reason for SRM development is magnetostatic interaction. The distinguishing features of the SRM mechanism are (i) the SD-NDS transition (Nekrasov, 1996) on the curves describing the magnetic moment as a function of temperature and the external magnetic field (e.g., an abnormal increase/decrease of the magnetic moment accompanied by absorption/ emission of thermal energy, a decrease in the SD-NDS transition temperature with increasing external field), and (ii) variation in the shape of the above curves as the environmental conditions change. One of the salient features of the SRM mechanism is the "Hopkins peak" of the non-existing mineral susceptibility as a function of temperature. The pre-magnetized IFGs in the NDS state show evidence of unidirectional anisotropy.

HIGH-TEMPERATURE MEMORY OF THE THERMOVISCOUS REMANENT MAGNETIZATION OF MAGNETITE-CONTAINING ROCKS

I.N.Petrov, V.V.Kaulio, V.A.Shashkanov (Earth Physics Department, Institute of Physics, Saint-Petersburg University, Saint-Petersburg, 198904, Russia)

Thermoviscous Remanent Magnetization (TVRM) was discovered and investigated by V.A.Shashkanov in 1971. This is a magnetization that appears while heating the rock in presence of direct magnetic field H till some temperature $T<T_c$ (where T_c - Curie point). It can be observed either at the temperature T or at room temperature after cooling specimen in H=0. **The phenomenon of high-temperature magnetic memory (α -memory)** was investigated by I.N.Petrov in 1986. The α -memory - phenomenon is the following: remanent magnetization of magnetite-containing rocks from hypergenesis zones does not decay fully after their heating till T_c and next cooling in H=0 to room temperature. Properties of the α -TVRM were investigated and discussed in this work. The remaining magnetization of this process was also named «α -memory». So **α -TVRM** - is the α - memory of TVRM. It is easy to see that the process of TVRM-acquisition may be expanded for temperatures $T>T_c$. For this temperatures it was shown that α -memory of TVRM is equivalent to the TVRM itself. It was shown that the value of a specimen α -TVRM remained after its first heating of a noticed kind is more large than α -TVRM after next heatings.

THE SINGLE-DOMAIN STATE - NONSINGLE-DOMAIN STATE TRANSITIONWITH REFERENCE TO SYNTHETIC AND NATURAL SAMPLES OF FE-TI OXIDES

A.N. Nekrasov (Institute of Experimental Mineralogy, Russian Academy of Sciences, Chernogolovka, Moscow district, 142432 Russia)

An abnormal increase/decrease in the sample magnetic moment and retardation of its heating/cooling rate are characteristic features of the single-domain (SD) state - nonsingle-domain (NSD) state transition, as shown earlier (Nekrasov, 1996). Theoretical assumptions have been verified experimentally by investigating the temperature dependence of magnetization in the magnetic field (H_e) using samples of synthetic inhomogeneous haemoilmenite of compositions $0.2 < X_{ilm} < 0.9$ and those of natural titanomagnetite with the compositions $0.2 < X_{mag} < 0.7$. The temperature of the SD-NSD transition (T_{SD-NSD}) decreases with increasing H_e and increases with increasing degree of chemical inhomogeneity of the investigated samples. The absolute value for the dT_{SD-NSD}/dH_e derivative varies directly with the value for the spontaneous magnetic moment. Similar results are obtained from other experimental data available in the literature. The experimental results are in good agreement with the theoretical assumptions following from the equilibrium equation for

DETECTION OF MAGNETISM CARRIERS IN ROCKS: RESULTS OF SUSCEPTIBILITY CHANGES OF MAGNETIC MINERALS INDUCED BY TEMPERATURE

O. Orlický (Geophysical Institute of the SAS, Dúbravská 9, 842 28 Bratislava, Slovakia)

The contribution presents the data from a number of natural as well as synthetic Fe and Fe-Ti oxides. The results were gained using the fully automated apparatus based on the measurements of temperature dependence of the low-field susceptibility (κ) of samples within the high-temperature interval as well as in the interval from liquid nitrogen temperature up to room temperature. The results of the Mössbauer spectroscopy of individual magnetic minerals will be presented as well. The specific Curie (or Neel) temperatures, phase transitions, chemical alterations and very fine differences in variation of κ with temperature have been used to detect respective magnetic minerals.

THE INTERACTION BETWEEN MICROSTRUCTURES AND MAGNETIC PROPERTIES OF IRON-BEARING OXIDE MINERALS

Andrew Putnis and Richard J. Harrison

Institut für Mineralogie, Universität Münster, 48149 Münster, GERMANY.

Interaction between magnetism and microstructure increases the stability of natural remanent magnetization. Microstructures visible by transmission electron microscopy (TEM) arise by phase transitions such as cation ordering, and also during the early stages of exsolution in solid solutions. Examples of the importance of these processes will be reviewed. (1) The origin of self-reversals in the system ilmenite-hematite is due to the presence of twin boundaries across which the Fe,Ti atoms are in antiphase ordering. (2) The consequences of spinodal decomposition of the ulvospinel-magnetite solid solution will also be discussed. (3) We describe recent experimental work on the magnetic properties of exsolved samples of the analogous system magnetite - spinel. Microstructures observed by TEM are correlated with coercivity and saturation magnetization measurements. Spinodal decomposition forms a phase which has reversed magnetization relative to the bulk of the sample. The pronounced coercivity and unusually high remanence at 4 K in these samples is characteristic of magnetization reversal by strongly pinned conventional domain walls. Above 100 K the coercivity and remanence are rapidly reduced, with hysteresis loops characteristic of magnetization reversal by weakly pinned interaction domain walls. This transition in domain state is related to the paramagnetic boundaries around the Fe-rich components of the compositional fluctuations.

SOME PECULIARITIES OF THE TRM-PROCESS OF THE FINE MAGNETITE GRAINS

Shashkanov V.A., Samsonov I.V., Kosterov A.A., Saushkina E.A., Petrov I.N.
(Physics Institute, SPb University, Ulyanovskaya,1, S-Petersburg, 198904,Russia)

Investigation of the complex of artificial sediments created for a wide range of the sedimentation conditions had allowed to estimate some aspects of the TRM-process of their magnetic particles. {Sets of artificial sediments have been created in horizontal sedimentation magnetic fields taken within interval: 0<H< 45 Oe for different initial magnetic states of magnetic particles in each set. As the initial magnetic states of magnetic grains there were chosen those with preliminary TRM's induced in the magnetic field $H_i \in$ 0-150 Oe. The magnetic grains were submicron magnetite particles extracted from iron ore deposit of Upoka (Karelia).} The analysis of data on both $\{I_{ro}(H)\}(Ht)$-dependencies of sediments and their orientational magnetic anisotropy curves had allowed to estimate the magnetic microstructure of the Upoka magnetite particles. They were determined as particles with 3 orthogonal axes of easy magnetization: but one of those three axis is the easiest of all of them (the main axis) with index of advantage: $\mathbf{k} = I_{rs}(\text{main})/I_{rs}(\text{secondary})$. - which was estimated to be equal $\mathbf{k} = 3.4$. All magnetic moments in all particles for ($H_t = 0$)-"thermomagnetizaton" are acquiring in the main magnetic axes. Then four modes of the DRM-process established for Upoka magnetite sediments allowed us to select four modes of TRM-process. Our phenomenological TRM-acquisition theory connects TRM behaviour with the magnetic moments distribution between main and secondary axes of particles.

MAGNETIC PROPERTIES OF ORDOVICIAN DOLOMITES IN ESTONIA: THE TOOL FOR THEIR GENESIS DETERMINATION

A. Shogenova (Institute of Geology, 7 Estonia Avenue, Tallinn EE0001, Estonia, e-mail: alla@gi.ee)

Magnetic susceptibility of Ordovician dolomites measured on more than one hundred of rock samples showed the diversity connected with dolomite genesis. Associated with fracture zones in Ordovician rocks secondary dolomites are characterised by increasing magnetic properties. The same was determined for spatial lower Ordovician dolomites and from this we could conclude their similar genesis. However these spatial dolomites were described by some authors as early diagenetic, by others as late diagenetic, appeared owing to metasomatic dolomitization. For decision of this problem and express determination of dolomite genesis we offer to use measurments of magnetic susceptibility. It was revealed that the magnetic susceptibility of Ordovician late diagenetic dolomites is higher than of primary dolomites, owing to substitution of Mg by Fe in the crystal lattice of secondary dolomites. Studied magnetic properties of Silurian dolomites are not controlled by their genesis.

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GYROREMANENT AND ROTATIONAL REMANENT MAGNETIZATIONS ACQUIRED BY SD GREIGITE: POTENTIAL APPLICATIONS

I.F. Snowball (Geological Survey of Finland, Betonimiehenkuja 4, 02150 Espoo, Finland)

Greigite acquires gyroremenant magnetization (GRM) and associated rotational remanent magnetization (RRM), a property that (based on work on magnetite) has been assigned to the presence of single-domain (SD) grains and a source of anisotropy. SEM/EDAX analysis of different samples of natural greigite demonstrates that the morphology of greigite can be quite variable, ranging from well crystallized individual isometric octahedra (*circa* 1 μm long) to interlocking plate-like crystals of variable size (maximum individual length *2-5* μm). Despite the variable morphology the M_{RS}/M_S ratio of randomly oriented collections of these grains consistently exceeds 0.5 (maximum of 0.7), which has been attributed to significant magnetocrystalline anisotropy. The gyrofield (*Bg*) produced at a slow rotation rate of 5 rps and 100 mT peak AF was *circa* 100 μT and the RRM possessed a MDF of *circa* 80 mT. These values are significantly higher than those obtained for other well characterized common magnetic minerals at the same rotation frequency and peak AF (e.g. SD bacterial magnetite, detrital magnetite, maghaemite, haematite and magnetic tapes). The diagnostic value of *Bg* and MDF_{RRM} as an indicator of the presence of greigite was shown by a study of sediment cores from Bara Mosse (southern Sweden).

THE FIELD DEPENDENCE OF THE ORIENTATIONAL MAGNETIC ANISOTROPY OF SEDIMENTS

Shashkanov V.A., Samsonov I.V., Kosterov A.A., Saushkina E.A., Petrov I.N.
(Physics Institute, SPb University, Ulyanovskaya,1, S-Petersburg, 198904, Russia)

Sets of artificial sediments have been created in horizontal sedimentation magnetic fields taken within interval: 0<H<45 Oe for different initial magnetic states of magnetic particles in each set. As the initial magnetic states of magnetic grains were chosen those with preliminary TRM's induced in the magnetic field H_i ($0 \le H_i \le 150$ Oe). The magnetic grains were submicron magnetite particles extracted from iron ore deposit of Upoka (Karelia). Their concentration in the sediments was taken about 0.7 weight percents. Analysis of the obtained experimental results allowed to conclude that: 1. All the complex of the sediment $\{I_{ro}(H)\}(Ht)$ - dependences had supported the Langevin's character [$I_{ro}(H) = I_{max} L(H)$] of curves $I_{ro}(H)$ and revealed some of their behavioural patterns, such as: 1) the monotonous increase of maximum magnetization I_{max} of Langevin's process take place for H_i from interval: $0.5 < H_i < 150$ Oe; 2) curve $I_{ro}(H)$ for $H_t = 0$ initial magnetic state of grains is the particular one. 2. The complex analysis of data on both $\{I_{ro}(H)\}(Ht)$ dependences of our sediments and their orientational magnetic anisotropy curves had allowed us: 1) to characterize the magnetic microstructure of the Upoka magnetite particles and 2) to formulate some elements of the phenomenological theory of TRM-process on them. 3. Four modes of the TRM-process, established for Upoka magnetite particles, allowed us to select four modes of DRM-process. These latters should be considered as the combination of processes TRM and DRM.

SEMI-QUANTITATIVE METHOD FOR THE STUDY OF HE MAGNETIC MINERALOGY OF A ROCK

. Winkler & L. Sagnotti
tituto Nazionale di Geofisica, Rome, Italy
. Lehman
entre des Faibles Radioactivite-Gif sur Yvette, France

owrie's method (1990) has been imposed as an agile technique for e study of the magnetic mineralogy of a rock. This method consists the determination of the magnetic mineralogy according to the iblocking temperatures and the coercivity spectra in a rock sample. this talk a new method of best fit analysis applied to Lowrie's ethod is discussed; this approach, particularly helpful for complex agnetic mineralogies, allows the evaluation of the percentage ontribution of each recognized magnetic phase to the composite othermal remanent magnetization (IRM) imposed to the investigated ck. A specific software has been developed to resolve the best-fit id to compute the related errors.

ANISOTROPY OF ISOTHERMAL REMANENT MAGNETIZATION FOR VARIOUS REMANENCE STATES OF MAGNETITE CONTAINING SPECIMENS

K. Zapletal, F. Hrouda and V. Jelínek (AGICO Inc., Jecná 29a, CZ-612 46 Brno, Czech Republic)

Anisotropy of isothermal remanent magnetization (AIRM) of artificial specimens with sized grains of natural magnetite was measured and computed using Jelínek method. Two kinds of the remanebility tensor (AIRM tensor) were computed from each AIRM measurement: the tensor of the 1st kind (linear approximation) and the tensor of the 2nd kind based on a new, non-linear IRM anisotropy model (Jelinek, 1996). The values of magnetizing fields used for AIRM measurements (ranging from 2 to 400 mT) were chosen after measuring the IRM acqisition curves for each specimen. The curves show multidomain behaviour of measured magnetite grains (the grain size is of order of 10 micrometers). From comparison of the AIRM with the anisotropy of low-field susceptibility (AMS) we can conclude: (1) The directions of principal remanebilities for different remanent states of the same specimen coincide each other and they are close to the directions of principal susceptibilities, with the exception of the AIRM principal directions for the saturated IRM field region. (2) The degree of anisotropy computed from the AIRM tensor of the 1st kind is generally much higher than the anisotropy degree derived from the AMS tensor. This difference is lower in the case of the 2nd kind AIRM tensor.

SE15 Rock- and palaeomagnetism and environmental magnetism

Convener: Hoffmann, V.

05 Biomagnetic materials: basic properties and applications

Convener: Gendler, T.
Co-Conveners: Maher, B.A.; Petersen, N.

DISSOLUTION OF BIOGENIC MAGNETITE IN ANOXIC MARINE SEDIMENTS

K. Däumler, H. Petermann & U. Bleil
(Fachbereich Geowissenschaften, Universität Bremen,
Postfach 330 440, D-28334 Bremen, FRG)

Biogenic magnetite synthesized by magnetotactic bacteria is the dominant carrier of magnetization in recent to sub-recent marine surface sediments of the Benguela upwelling system off Namibia. Concentrations of terrigenous magnetic minerals are relatively low in this region compared to other hemipelagic sediments in the South Atlantic.
The preservation of the fine-grained bacterial magnetite is very short-lived in these sediments however. The high productivity area provides a strongly reducing environment driven by the high supply of organic matter to the sediment and high sedimentation rates.
Electron microscope examination of magnetic extracts exhibits high concentrations of biogenic magnetosomes in the top samples. At 5 to 6 cm depth, the bacterial magnetites are corroded, further down they are dissolved.
Magnetization intensities, with maximum values in 2 cm below sediment surface, show drastic decreases within the upper 3 to 7 cm, coupled to a (stepwise) transition from mainly single-domain behaviour in the top centimeters and SP/SD characteristics beneath to multi-domain properties in deeper strata.

CONTRAST MECHANISM OF DOMAIN IMAGES THROUGH MAGNETOTACTIC BACTERIA

K.Futschik, H. Pfützner, G.Harasko (Institute of Fundamentals and Theory of Electrotechnics, Bioelectricity & Magnetism Div., Univ. of Technology, Vienna)

As well known, soft magnetic materials - as used for electrical machine cores - exhibit so-called magnetic domains which determine the magnetic behaviour in a distinct way and thus are of great practical relevance. Domain analyses can make use of stray fields generated by the domains, however being complicated by very small field intensities. In former work we showed that magnetotactic bacteria (MBs) can be applied as very effective "sensors" for these fields. In the present study, various species of MBs were investigated for their applicability for nondestructive domain analysis of coated SiFe sheets and amorphous Co-based ribbons. Investigations showed that only magnetotactic cocci which show a definite swimming direction are suitable for this purpose. In comparison with colloid techniques which allow visualisation of domain images in distances of 5 μm, MBs show effectivity up to 500 μm from the specimen surface. A "domain viewer" was developed which allows bacteria reuse. It is applied to the specimen's surface and can easily be shifted to different regions. The basic principle of the contrast mechanism is that MBs propel themselves in the direction of field lines getting concentrated in the center of each second domain exhibiting a surface south pole. A closer study of the mechanism shows that the MB motion is distinctly influenced by thermal energy. A computer program for the simulation of time-spatial bacteria distributions over domains is presented which allows an understanding of the influence of different parameters (bacteria concentration, domain width, Brownian motion) on the contrast. Comparisons of simulation results and experimental results illustrate the model's effectivity.

INFLUENCE OF FE-CLAY MINERALS STRUCTURE ON MICROBIAL ABILITY TO TRANSFORM OF FINE DISPERSED FE-OXIDES AND HYDROXIDES . THE MODELING EXPERIMENTS.

T.S.Gendler (UIPE, B.Gruzinskaja 10, 123810 Moscow, Russia) , L.S.Il'ina, A.A.Novakova (Moscow State University, 117234 Moscow, Russia), I.A.Avenarius (MARI, Moscow, Russia)

One of the critical point at discussing of biogenic magnetite origin is the pathway of necessary Fe(II) -ions creating . Fe(III) from clay minerals and hydroxides can be looked as the most abundant and potential electron accepter in most soils and sediments. This work is the experimental modelling of one of the possible stage of Fe(III)- reduction . Montmorrilonite (M) was chosen as one of the main soil clay mineral posessing a high cation exchange capacity . Amorphous ferric hydroxides was precipitated on the M surface from Fe57Cl3 solution at pH~1, then washed at pH~ 5.5 and dried in air. Some of batches were heated at 300 and 1000oC to form fine dispersed hematite particles and destroy of M swelling capacity. Then all the samples were incubated in 1% sucrose solution (1-3 month) what is a nutrient medium for growth of non-specific microflora. Precipitates were studied by Mossbauer spectroscopy (MS), X-ray and rock magnetic methods in initial state and after treatment by oxalate and dithionite agents. Analysis of MS data showed Fe57(III) ions presence on the surface and in interlayer space. The incubation in sucrose solution resulted in partial dissolution of surface hydroxide particles , reduction of Fe(III) interlayer ions and IRM appearance. No evident reducing effect of microorganisms on the same samples heated before incubation.

SPATIAL ARRANGEMENT OF CHAINS OF MAGNETOSOMES IN MAGNETOTACTIC BACTERIA: I OBSERVATIONS

M. Hanzlik, M. Winklhofer, N. Petersen (München)

Scanning and transmission electron microscopy (SEM/TEM) was used to investigate the spatial arrangement of chains of magnetosomes in cells of two morphologically different types of magnetotactic bacteria which possess at least two chains: Magnetobacterium bavaricum, and wildtype magnetic cocci. The TEM pictures show apparently very different arrangements of the chains within the cells. Stereo micrographs obtained by tilting individual bacteria in the TEM, however, revealed that magnetosome chains in magnetic cocci always lie on opposite sides of the cell body and in close proximity to the cell envelope. The rod-shaped cells of M. Bavaricum contain up to 1000 bullet-shaped magnetosomes forming 3 to 5 rope-shaped bundles of magnetosomes arranged such that they are separated by the maximum possible distance from each other and positioned adjacent to the cell envelope. These observations can be understood in terms of repulsion forces between parallel magnetic dipoles driving the chains apart from each other and forcing them to be in direct mechanical contact to the cell envelope. Thus, the magnetic torque on the chains exerted by the geomagnetic field can be transferred very effectively to the whole cell body.

THE MORPHOLOGICAL STRUCTURE OF A POSSIBLE MAGNETITE BASED MAGNETORECEPT OR IN BIRDS

E. Holtkamp-Rötzler, G. Fleissner (Frankfurt), M. Hanzlik, N. Petersen (München)

A variety of behavioral experiments indicate that homing pigeons (*Columba livia*) and other avian species are sensitive to small changes ($< 0.1\,\%$) in the ambient magnetic field. This ability has been proposed as the basis of an avigational map used for homing and migration. The mechanisms by which birds detect such small field changes and transduce this information to the nervous system are still unknown.
Neuronal correlatives of the map system might be associated with magnetite in connection to trigeminal nerve fibres in the upper beak area of birds. In the present study, iron-oxide - probably magnetite - has been found in the upper beak-skin of pigeons. Histological investigations with the prussian-blue staining method show Fe-III-oxide particles in the upper beak skin embedded between pressure receptors (Merkel cells) and in connection with unmyelated fibres of the ophthalmic nerve.
By means of special electronmicroscopical methods (SAD) and magnetic measurements using a SQUID-magnetometer, the particles were identified as magnetites in the SP-SD grain size range, which may be capable of sensing small intensity changes of the magnetic field. A magnetotransducer mechanism could be described with these modified pressure receptors (Merkel cells with magnetite) in birds.

THE MODEL OF INDUCTIVE FERROMAGNETIC BIORECEPTOR

P.V.Kharitonsky, J.G.Voronina (Dept. of Physics, Far Eastern State University, 8 Sukhanova str., Vladivostok 690 600, Russia)

The model of magnetoreceptor, which consists of a biomatrix with scattered magnetite grains in it, is proposed. This model doesn't require a direct contact with the nerve endings. Physical mechanism of signal transfer is based on the electromagnetic induction. It is supposed, that environment of a biomatrix is viscous and a free rotation of grains does not occur. The magnetization in the weak geomagnetic field is arisen due to the magnetostatic interaction fields. A distribution function of interaction fields is considered normal for the concentration of ferromagnetic more than 10%. Even if dielectric environment is water (i.e. μ=1) it is shown that the induced electric field is in order 2-7μV/m. According to the experiments (R.W.Murrey, J.Physiol. 1980, A.L.Kalmijn, Science, 1982.) such an electric field can be indicated by the nerve system of alive organism. The optimum parameters of the receptor of cylindrical shape were found. The height of cylinder must be much less than its radius in case of concentration of magnetite about 10%. The height is approximately equal radius for 20-25%. The first case is more advantageous with point ofview "economy" of material.

THE SIGNIFICANCE OF MAGNETOTACTIC BACTERIA FOR THE MAGNETIC RECORD OF QUATERNARY SEDIMENTS AND SOILS

B.A. Maher, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, U.K.

Rock magnetic characterisation of sediments is unable as yet to make an unequivocal identification of the presence of ferrimagnetic magnetosomes (i.e. produced intracellularly by magnetotactic bacteria). Conversely, magnetic extraction methods have been shown to be rather efficient in concentrating such grains by their removal from the less-magnetic sedimentary matrix; their identification under electron microscopy is also straightforward given their cha racteristic size, shapes and (frequent) concatenation. Bacterial magnetosomes have been found in a diverse range of modern environments. They have also been found as fossils in a wide range of geological sediments. However, their significance - in terms of their abundance and their contribution to the magnetic properties of sediments - also varies widely, as will be shown for some deep-sea sedimentary sequences and soils and palaeosols.

PRELIMINARY INVESTIGATIONS ON MAGNETOTACTIC BACTERIA IN VIETNAM

V. H. Nam (Hanoi)

The research on magnetotactic bacteria in Vietnam has begun in 1993. Vietnam is an ideal place to study the dependency of type and concentration of magnetic bacteria on the Earth's magnetic field: The southernmost tip of Vietnam touches the magnetic equator (inclination I=0°) while in the northern part of the country the inclination is about 35°.
The research in a profile along Vietnam territory showed that magnetic bacteria are widely distributed in limnic and marine environments. In HoChiMinh City (I=6.3°), we observed only North-seeking magnetic bacteria, while in the area of Baclieu near the geomagnetic equator (I=2.3°) both North-seeking and South-seeking types with roughly equal numbers were found.
The investigation on environmental parameters showed that magnetic bacteria occur near the water-sediment surface where pH $\approx$ 6.5 -7.5 and DO $\approx$ 6 mg/l. The magnetic bacteria found in Hanoi are diverse in shape and size. The magnetic particles are arranged in chains (1-6 chains per cell), each chain contains 5-20 species-specific magnetic particles.

THE INFLUENCE OF WATER MEDIUM pH ON THE BACTERIAL IRON REDUCTION AND MAGNETIC MINERALS FORMATION.

A.A.Novakova, S.A.Pargamotnicas (Moscow State University, 117234 Moscow, Russia), V.Taseva (Bourgas Technological University, 8010 Bourgas, Bulgaria), T.S.Gendler (UIPE, 123810 Moscow, Russia).

The analysis of corrosion sediments formed under vital activity of biofilm created on the surface of mild steel coupons was performed in recent work. These coupons were placed in the different points of the real cooling water system and used as collectors of biofilm in a Biological Test apparatus. The samples under investigation had varied pH of water medium as well as exposition time. Mossbauer spectroscopy, combined with X-ray diffraction and thermomagnetic analysis were used. The chemical analysis of water and microbiological analysis of the biofilms were performed also. Our study has shown the presence of different compounds on the surface of steel. Only CaCO3 is in crystalline form. The other compounds: FeOOH, Fe2O3, Fe3O4, FeS2 and Fe7S8 are in fine dispersed form. We examined the influence of water medium pH on the activity of different bacterial types by means of analysis of various magnetic minerals formation in corrosion sediments.

MAGNETOTACTIC BACTERIA - A FAST TECHNIQUE OF VISUALISING REMANENCE CARRIERS IN ROCKS

E. Petrovský (Geophysical Institute, Boční II, 141 31 Prague 4, Czech Republic)
V. Hoffmann (Institut für Allgemeine und Angewandte Geophysik, Universität München, Germany)
M. Funaki (National Institute of Polar Research, Tokyo, Japan)
A. Ambatiello (Institut für Allgemeine und Angewandte Geophysik, Universität München, Germany)
A. Kapička (Geophysical Institute, Boční II, 141 31 Prague 4, Czech Republic)

Direct optical determination of remanence carriers in rocks is of great importance to rock- and palaeomagnetists. Several techniques, more or less demanding, have been used to visualise magnetic microstructures on polished surface of rock samples. In our contribution, a technique is demonstrated, using magnetotactic bacteria as sensors being sensitive to magnetic surface poles, on rock samples containing pyrrhotite (Fe_7S_8). This method will be compared with data obtained on the same particles using classical Bitter technique and magnetooptical Kerr effect and *pro et con* will be summarised. Magnetic bacteria can be used as sensors even more sensitive to weak magnetic fields than commercial ferrofluids as used by the Bitter technique. On the other hand, lower resolution does not allow detailed observations of domain structures on magnetic minerals. Our results suggest that magnetotactic bacteria can be used as a fast, low-priced method of detecting magnetic grains on polished surface of rocks.

PRESENCE OF BIOGENIC MAGNETITE IN HUMAN ORGANS

P. P. Schultheiss-Grassi and F. Heller (Institut für Geophysik, ETH Hönggerberg, CH-8093 Zürich, Switzerland)
M. A. Klein (Institut für Neuropathologie, Dept. Pathologie, Universitätspital, CH-8091 Zürich, Switzerland)
J. P. Dobson (Dept. of Physics, Biophysics Programme, University of Western Australia, Nedlands, WA-6907 Perth, Australia)
H. G. Wieser (Neurologische Klinik, Universitätspital Zürich, CH-8091 Zürich, Switzerland)

IRM acquisition and AF demagnetization analyses were performed on human hippocampal tissue resected during operations performed on patients with Mesial Temporal Lobe Epilepsy. Tissue samples from the human hippocampus, basalganglia, cortex, cerebellum, leptomeninges, heart, spleen and liver were resected from cadavers with different pathologies and also analyzed by these methods. The samples were measured at both 77 K and 273 K. AF demagnetization was performed at 273 K. Results of the magnetic analyses of the brain tissue, as well as of the heart, spleen and liver, indicate the presence of ferrimagnetic fine-grained, magnetically interacting particles (magnetite and/or maghemite). The presence of superparamagnetic particles can be inferred from the increase in saturation IRM values when measured at 77 K compared to measurements at 273 K. The concentration of magnetite in the samples varies from 4 ng/g to 300 ng/g, with the heart tissue having generally the highest concentrations.

SPATIAL ARRANGEMENT OF CHAINS OF MAGNETOSOMES IN MAGNETOTACTIC BACTERIA: II MODELLING

M. Winklhofer, M. Hanzlik, N. Petersen (München)

Theoretical modelling was carried out to explain the observations presented in the paper by M. Hanzlik *et al.* In magnetotactic bacteria containing at least two chains of magnetosomes, the chains are separated by the maximum possible distance from each other and positioned adjacent to the cell envelope. This can be understood in terms of magnetic repulsion between the parallel lines of dipoles, which drives the chains apart from each other and thereby forces them to be in direct mechanical contact to the cell envelope. An interesting phenomenon is observed in magnetic cocci containing two double-chains of magnetosomes. Here a displacement of the chains of about half the length of a single magnetosome is observed. In such a case at distances small compared to the length of the chains, the magnetic force between the two chains becomes attractive and increases with decreasing distance between the chains. This means that the arrangement of double-chains as observed in certain cocci forms a stable configuration. The constitution of more than one chain of magnetosomes in a bacterium is a very effective means to achieve a sufficiently high magnetic moment for a given cell size to overcome the viscous resistance with respect to the surrounding medium, which is required to ensure an alignment with the geomagnetic field as fast as possible.

MAGNETIC MEASUREMENTS ON INDIVIDUAL MAGNETOTACTIC BACTERIA

M. Winklhofer, M. Hanzlik, N. Petersen (München)

We report on pulsed-magnetic-field remanence measurements on individual cells of *Magnetobacterium Bavaricum*, a magnetotactic rod with three up to five chains of magnetosomes. A dead cell aligned in a weak field is subjected to an increasing series of magnetic field pulses ranging from 200 G to 800 G in order to determine the field necessary to revert direction of magnetization. After each pulse the magnetic moment of the cell is determined using the rotating field method in the bacteriodrome. The so obtained curves of remanent magnetization are not square indicating that a single bacterium can be demagnetized. This is in marked contrast to cells of magnetic spirilli and vibrios containing only one linear chain of magnetosomes, the magnetization of which only can have two discrete values, that is $+M_s$ or $-M_s$. Moreover, the values of the remanence coercive forces ($H_{rc} \sim 600$ G) determined here are considerably higher than the magnetization reversal fields ($H_s \sim 300$ G) of spirilli and vibrios. This enhanced stability of magnetic remanence of *M. Bavaricum* with respect to reversal of magnetization is a consequence of its extremely long chains, each of which can be considered as a high-coercive needle of magnetite. The results of our experiments are complemented by a three-dimensional micromagnetic model.

SE16/G15 Potential fields in geophysics and geodesy

Convener: Jacoby, W.R.
Co-Conveners: Braitenberg, C.; Groten, E.

THE USE OF POTENTIAL FUNCTIONS TO MODEL THE SOURCES OF SOME MAGNETIC ANOMALIES OF THE TERESTRIAL MAGNETIC FIELD.

T. Bicskei (Geomagnetic institute,11306 Grocka,Yugoslavia)

Starting from appropirate Fourier representation of the potential function, it is possible to derive a set of potential functions which describe at the same time the source as well as the corresponding field, at optional distance, too. Appropriate parametrization makes it possible to evaluate the parameters of used mathematical model on the basis of measured field data collected at optional distance from a field source.

ONE MODIFICATION OF THE NEWTON'S METHOD - CONJUGATE GRADIENTS SOLUTION IN INVERSE GRAVIMETRIC PROBLEMS SOLUTION

L.V.Babenko (Inst. of Geophysics, Nat Ac Sci Ukr, Kyiv-142, Ukraine 252142)

A method of solving the problem of multiparametrical functional minimization $F(d^*)=\min F(d)$ based on the adaption sistem of the Newton's operation process of finding minimum function $F(d)$ and one modification of conjugate gradients method for a system of linear algebraic equationes is proposed. Here $F(d)$ - is the mearsquare differens between the observed and theoretical anomalous fields, d^* - is the desired parametries vector of the geological scheme. At each step of Newton's iteration process a certain sperially conatructud equivalent system of linear equations is solved by method of conjugate gradients. The convergence of iteration process for the constructed calculation scheme is proved at any initial approximation. This method allows to receive the solutions at presence of special points. On a model examples advantages of the built its sxion process is compared with straight methods (Gauss method) of solving systems of linear algebraic equations are discussed. The materials of the report were described in details in article L.V.Babenko "Regularise Newton's method of conjugate gradients for solving inverse gravimetric problem" - Geophysical Journal, 1990, v.12, Ni.

DETERMINING THE MAGNETIC FIELD ON THE EARTH'S CORE-MANTLE BOUNDARY

L. Ballani, D. Stromeyer and H. Greiner-Mai (GeoForschungsZentrum Potsdam,Telegrafenberg A17, D-14473 Potsdam, Germany)

Earth rotation and geomagnetic field are clearly correlated in the decade periode range (10 y - 100 y). The main mechanism assumed to be responsible for this is the electromagnetic core-mantle coupling. Its modelling requires the calculation of the time-dependent variable magnetic field on the core-mantle surface using time series of the outer surface magnetic field as boundary values. The problem of determining the inner boundary values of the magnetic field is of the same type as the "inverse Heat Conduction Problem", which is known to be extremely ill-posed.
In the present study we develop an adapted regularizing solution procedure based on modern theoretical stability estimations and using a boundary-control approach. If the analysis is restricted to periodic variations, the inverse problem simplifies considerably and estimates of the lower-mantle electrical conductivity can be found.
Using these approaches, we invert selected components of the spherical-harmonic expansion of the global geomagnetic field covering a time interval of about 100 y and discuss the time behaviour of the solutions.

SOME CONTINUATION FORMULAE FOR THE GEOMAGNETIC FIELD, BASED ON THE USE OF POTENTIAL FUNCTION AND ITS DERIVATES.

T. Bicskei (Geomagnetic institute,11306 Grocka,Yugoslavia)

Starting from potential function usually used for analytical description of the geomagnetic field, a set of continuation formulae has been derived which allows upword or downword continuation of the considered field in a presence of uneven topography.

THE INTEGRAL REPRESENTATION OF THE SPHERICAL-HARMONIC FUNCTIONS AND THEIR FOURIER TRANSFORM.

T. Bicskei (Geomagnetic institute,11306 Grocka,Yugoslavia)

Starting from Green's function, its usually used complex-valued spherical-harmonic expansion and corresponding Fourier transform, it is possible to derive a close form Fourier integral expression for all spherical-harmonic terms and define the relevant Fourier transforms.
The subject of this review is to derive the mentioned Fourier coefficients and to show how they correspond to the relevant harmonics. The results of this analysis are very usefull to determinate the vawe-lenght characteristics of the potential function by means of a spherical-harmonic terms. To illustrate it, the modell of the geomagnetic reference field (IGRF) potentialis analyzed.

ON THE POISSON RELATION BETWEEN THE GRAVITY AND THE MAGNETIC FIELD OF MAGNETIZED BODIES

F.Bocchio (Dipartimento di Georisorse e Territorio, Università di Udine ,Italy)

The so-called Poisson relation between the magnetic properties of a uniformly magnetized body of constant density and its gravity field has been investigated; in particular, since this relation actually holds between the magnetic field intensity and the directional derivative of the gravitational force vector, we are concerned, as a matter of fact, with the properties of the tensor of gravitational gradients due to the body, which gives rise to a constraining condition on the values of the magnetic field intensity at space points equidistant from the center of mass of the body along a set of orthogonal axes .

HELMHOLTZ AND THE TIDAL DISTORTION

RC Bostrom, Un. of Washington AJ-20, Seattle, WA 98195; bostromrc@aol.com

Von Helmholtz was concerned with matters other than the bodily tide, among others with identifying the conservation of energy. His 1857 identification of flow not under a velocity-potential demonstrates that the major earth tides cannot be formulated as for 70 yrs, in terms of the astrononomical potential acting on a stationary, passive earth. The potential is real, but relative to it the earth rotates. Models have constructed the M_2 bulge in the shape of a reversing spheroidal eigenvibration, rather than in reality as a wave moving continuously around the Earth. The wave is intrinsically a product of rotating, not reversing, stress axes. In comparison with the 'wave' tides M_2 and S_2, spheroidal tides are insignificant. Displacement and dissipation are a function of *cumulative* distortion. This is a separate entity, functionally independent of deformation which excludes solid-body rotation, and cannot be derived from it. In his historical review Hans Lugt (1979) points to reluctance to accept Helmholtz's non-potential flow, although it was immediately accepted by Kelvin (1859). Euler had already employed the concept. In a sense it makes possible modern fluid dynamics. Perhaps it is time to update our model of the tidal earth. In practice: 1 The rotational tilt-meter trace directly signals the prevalence of 'Helmholtzian' rotational-flow. It cannot be produced by stationary spheroidal deformation. 2 In an Earth pre-strained to failure under vortical flow (convection), there seems no reason why dissipation under the superposed M_2 wave should be incompatible with the phase lag observed in gravimetric data. 3 It is infeasible to apportion TOPEX/POSEIDON data between sea surface and seafloor using models not describing the bodily tide.

SPECTRAL METHODS IN GRAVITY INVERSION

C.Braitenberg and M. Zadro (Dipartimento di Scienze della Terra, Universita' di Trieste, Via E.Weiss 1, 34100 Trieste, Italy)

In diverse geophysical situations crustal superficial density anomalies as due to faults, dikes, cavities, inhomogeneities connected to volcanism, can be modelled as being constituted of one or more geometric elementary bodies. The bodies we are concerned with are the sphere, the cylinder, and an arbitrarily shaped right or inclined prism. Deeper lying density variations, as the Moho and the base of the lithosphere, can be modelled as an undulated sheet posed at a certain depth. We have undertaken a comprehensive study of the 3D spectrum of the potential and gravity fields for the above cited model situations. For each of the geometrical bodies we give closed formulas for the geometrical dimensions and depth of the body, in relation to its spectral field. In the case of the deep seated structure, the inversion method is used for retrieving the undulation of the surface, a method which also takes into account the continuation of the field. Next to synthetic model situations, we apply our relations also to observed field data.

THE ALGORITHMIC AND PROGRAM QUESTIONS OF SOLUTION OF THE INVERSE PROBLEM OF GRAVIMETRY AND MAGNITOMETRY BY THE SELECTION METHOD

E.Y.Bulach, M.N.Markova, N.A.Yakymchuk
(Institute of Geophysics, pr.Palladina, 32, Kiev-142, Ukraine)

The inverse problems are solved in the beforehand selected model class.It is necessary to constract a geological model and to calculate a theoretical anomalous field.The problem's solution is conserned with minimization multiparameter functionals. It was faund in practical calculation that structure functinal quite complex.The different ways of minimization of the qullied functionals are devised.The initial field contein a background component. In this case the solution is made in such way a background be excluded in the calculation cycle. Some transformants dicrease a background effect. The questions of the uniqness of the solution of the inverse problem are considered.

TIDAL FRICTION AND THE EVOLUTION OF THE EARTH'S FIGURE AND INNER STRUCTURE

C. Denis (Institut d'Astrophysique, 5, av. de Cointe, B-4000 Liège, Belgium)
P. Varga (GGRI, POB 5, H-9401 Sopron, Hungary)

Tidal friction determines to a large extent the mechanical evolution of the Earth–Moon system and is responsible for a secular increase of the length of the day (LOD). On the basis of palaeontological and palaeosedimentary information we infer an average rate $d\Delta\mathrm{LOD}/dt \approx 1.8$ ms/cy in the Phanerozoic. From a sparse number of data, we tentatively infer $d\Delta\mathrm{LOD}/dt \approx 0.35$ ms/cy in the Proterozoic. Moreover, there is definite evidence that the actual rate of change of LOD during the Phanerozoic was not constant, but was modulated by the evolving configuration of oceans. Assuming a specific law of variation of LOD throughout the geological past, we model the time variations of the Earth's shape and draw a number of conclusions concerning palaeotectonics. We provide values for geokinetic parameters as a function of time. In particular, the geometrical surface flattening has decreased from 0.005 to 0.003 over the last 2.5×10^9 years. The associated secular increase rate of the normal gravity component at the equator is about 2 nGal/yr. If tidal friction were the only cause of changes in LOD, $d\Delta\mathrm{LOD}/dt$ should have been *larger*, not five times smaller during the Proterozoic than during the Phanerozoic. Ongoing core formation throughout the Proterozoic may provide an explanation of this paradox.

FUTURE ASTRO-GEODETIC FIELD WORK BY CCD

Gottfried Gerstbach (Institute of Geodesy and Geophysics, TU Vienna, Gusshausstr. 27-29/128, A-1040 Wien, Österreich.

Astrogeodetic field work mainly concerns observations of vertical deflections and of astronomical azimuths. The former are the basis of astrogeodetic geoid solutions, the latter of geodetic network control. Both types of observations have gone down in the last decade because up to now they are not fully automated. CCD (charge coupled devices) will change this situation.

Based upon astrometry of satellites and stars the author analyses the use of CCD for astro-geodetic measurements. Automation and speeding up will be possible in a few years, the latter depending on the observation scheme. Sensor characteristics, cooling and reading out of the devices should be harmonized.

Using CCD *line sensors* in small prism astrolabes, the accuracy of vertical deflections will reach the visual one (±0.3" in 1 hour) within 3 years. Further it is planned to equip a transportable zenith camera with a CCD *array* (2048² pixels à 24 μm); presently a 75cm camera gives ±0.5". Azimuth observations of Polaris can be automated likewise by modern videotheodolites. Observations at daylight (sun, bright stars) would be much more difficult (high photon level, low contrast, sensor graduation) but may succeed a few years later by flexible software (macros, filters...).

Automation by CCD will speed up the observations, drops some errors (e.g. reaction time) and reduces the demand of personal experience. Together with GPS, Inertial Survey, gradiometry and other new techniques a real *Integrated Geodesy* will be established, combining classical and space methods with engineering survey and gravity field monitoring.

THE ABEL-POISSON KERNEL AND THE ABEL-POISSON INTEGRAL IN A MOVING TANGENT SPACE

E.W. Grafarend (Department of Geodetic Science, University of Stuttgart, Keplerstr. 11, D–70174 Stuttgart, Germany)

The upward-downward continuation of a *harmonic function* like the gravitational potential is conventionally based on the direct-inverse *Abel-Poisson integral* with respect to a sphere of reference. Here we aim at an error estimation of the "*planar approximation*" of the *Abel-Poisson kernel* which is often used due to its *convolution form*. Such a convolution form is a prerequisite to apply *Fast Fourier Transformation* techniques. By means of oblique azimuthal map projections/ projections onto the local tangent plane at *an evaluation point* of the reference sphere of type "*equidistant*","*conformal*" or "*equiareal*" we arrive at a rigorous transformation of the *Abel-Poisson Kernel / Abel-Poisson integral* in a *convolution form*. As soon as we expand the "*equiareal*" *Abel-Poisson kernel / Abel-Poisson integral* we gain the "*planar approximation*". Six configurations are studied in all details in order to document the error budget varying from *1%* for points at the spherical height $H = 10km$ above the terrestrial reference sphere up to *96%* for points at the spherical height $H = 6.3 \times 10^6$ *km*.

WAVELET ANALYSIS FOR REGIONAL-RESIDUAL SEPARATION OF POTENTIAL FIELDS

Maurizio Fedi (Dipartimento di Geofisica e Vulcanologia, Largo San Marcellino 10 - Universita' di Napoli Federico II - 80138 Napoli-Italia)
Tatiana Quarta (Dipartimento di Scienza dei Materiali- Universita' di Lecce, via per Arnesano 73100 Lecce-Italia)

The target of the gravity or magnetic research is the physical definition of density and magnetization distributions from their relative fields, i.e. the estimation of source parameters such as depth, density and volume. This is a complex task, since the gravity and the magnetic fields of the Earth are both integral effects of a number of physical sources. It follows that anomalies resulting from the superposition of many source effects can not be uniquely separated into a set of single-source anomalies. Normally, the regional-residual separation of the field has been attempted in two ways: a) enhancing the regional or the residual part of the signal, respectively; b) modelling the two parts of the field by Fourier approximation or by other types of orthonormal bases of functions. To this end, we present a method based on the discrete wavelet transform. Application of the technique to both synthetical and real cases shows that, differently from the Fourier method, an optimal frequency-space localization may be achieved, which allow a more consistent regional-residual separation of the field.

THE STOKES AND VENING–MEINESZ FUNCTIONALS IN A MOVING TANGENT SPACE

E.W. Grafarend and F.Krumm (Department of Geodetic Science, University of Stuttgart, Keplerstr. 11, D–70174 Stuttgart, Germany)

The regularized solution of the external spherical *Stokes boundary value problem* as being used for computations of geoid undulations and deflections of the vertical is based upon the *Green functions* $S_1(\Lambda_0, \Phi_0, \Lambda, \Phi)$ and $V_1(\Lambda_0, \Phi_0, \Lambda, \Phi)$ which depend on the *evaluation point* $\{\Lambda_0, \Phi_0\} \in S^2_{R_0}$ and the *sampling point* $\{\Lambda, \Phi\}$ of *gravity anomalies* $\Delta\gamma(\Lambda, \Phi)$ with respect to a normal gravitational field of type gm/R ("free air anomaly"). If the evaluation point is taken as the meta–north pole of the *Stokes reference sphere* $S^2_{R_0}$, the *Stokes function*, and the *Vening-Meinesz function*, respectively, takes the form $S_2(\Psi)$, and $V_2(\Psi)$, respectively, as soon as we introduce {meta–longitude (*azimuth*), meta–colatitude (*spherical distance*)}. In order to derive *Stokes functions* and *Vening-Meinesz functions* as well as their integrals, the *Stokes* and *Vening-Meinesz functionals*, in a *convolutive form* we map the sampling point $\{\Lambda, \Phi\}$ onto the tangent plane $T_0 S^2_{R_0}$ at $\{\Lambda_0, \Phi_0\}$ by means of *oblique map projections* of type equidistant (*Riemann* polar/normal coordinates), conformal and equiareal. The difference between the *Stokes functions / Vening-Meinesz functions* and *their first terms* (only used in the Flat Fourier Transforms of type FAST and FASZ), illustrate the systematic errors in the *"flat"Stokes function* $2/\Psi$ or "flat" *Vening-Meinesz function* $-2/\Psi^2$. The newly derived *Stokes functions* $S_3(r), \ldots, S_6(r)$, of *Stokes integrals* as well as *Vening-Meinesz* functions $V_3(r), \ldots, V_6(r)$, of *Vening-Meinesz integrals* – all of convolutive type – pave the way for the rigorous *Fast Fourier Transform* and the rigorous *Wavelet Transform* of the *Stokes integral* / the *Vening-Meinesz integral* of type "*equidistant*", "*conformal*" and "*equiareal*".

Initial-Value Techniques as Applied to Viscoelastic Deformation with Internal Density Jumps

Ladislav Hanyk, Dept. Geophysics, Charles University, 18000 Prague, 8,Czech Republic. David A. Yuen, Minnesota Supercomputer Institute, Univ. Minnesota, Minneapolis, MN 55415-1227, U.S.A. Ctirad Matyska and Zdenek Martinec, Dept. Geophysics, Charles University, 18000 Prague, 8, Czech Republic

We have employed a recently developed initial-value method applied to small-amplitude viscoelastic deformations for a self-gravitating, radially heterogeneous,compressible model.The problem of visco-elastic deformation with internal boundaries in the Earth's interior must be treated with care. Density jumps in the mantle can be interpreted as being attributed to compositional differences or to phase transitions. The boundary conditions at any internal boundaries with a density jump are different for the two cases. The main difference comes in the mass-conservation equation, where the product of the density times the radial displacement must be continuous across the phase boundary , whereas for a chemical boundary only the radial displacement needs to be continuous. There are large differences (50%) between compressible and incompressible models for the low degree harmonic.This would mean that any metastable phase transitions would have more of an effect on long-wavelength signals, since the transient effects of the 400 km phase change are really significant.

TOPOLOGICAL CHARACTERISTICS OF MAGNETIC AND OTHER SOLENOIDAL VECTOR FIELDS

R.Hide (Dept. of Physics. University, Oxford OX1 3PU, England, U.K.)
D.R.Barraclough & S.Macmillan (Geomagnetism Unit, British Geological Survey (NERC), Edinburgh, Scotland, U.K.)

Of both theoretical and practical interest are investigations of the general topological characteristics of solenoidal vector fields such as a magnetic field $\boldsymbol{B}$, for which div $\boldsymbol{B} = 0$. On any closed surface there are two or more "dip-poles" (where $\boldsymbol{B}$ is normal to the surface) and one or more "null-flux (C) lines" (where the normal component of $\boldsymbol{B}$ vanishes). In addition, in all but the simplest configurations of $\boldsymbol{B}$ (such as when $\boldsymbol{B}$ has an axis of symmetry) there are "touch-points" on some of the C-lines, where $\boldsymbol{B}$ is tangential to the C-line. It has been conjectured: (a) that these three features on suitably-chosen closed surfaces suffice to characterise any magnetic field topologically, and (b) that self-exciting magnetohydrodynamic (MHD) dynamo action always produces magnetic fields for which it is possible to find some closed surface upon which there are touch points and a suitable number of "non-nested" C-lines (Hide R., *JGR* **86**, 11,681, 1981; *QJRAS* **27**, 3, 1986). In this paper we present maps of these topological elements of the geomagnetic field at various levels above the core-mantle boundary, hoping that the results will facilitate future work on the validity or otherwise of the conjectures, and on the formulation of diagnostic schemes for dealing with the output of numerical models of MHD dynamos, which could be used to test the conjectures.

STRUCTURAL EFFECTS OF THE CRUST ON THE GEOID MODELLED BY USING DEEP SEISMIC SOUNDING INTERPRETATIONS

J. Kakkuri and Z. Wang, Finnish Geodetic Institute

According to the theory of isostasy, the Earth have a tendency to deform its surface in order to reach an equilibrium stage. The land uplift phenomenon of the Fennoscandian Shield is thought to be this kind of process. The geoid, as an equipotential surface of the Earth's gravity field, is just a measure of how much the Earth surface departs from the equilibrium stage. In order to study the isostatic process through the geoid undulations, the structural effects of the crust on the geoid have to be known. The crustal structure in the Fennoscandian Shield have been extensively explored by means of Deep Seismic Sounding(DSS). The data obtained from DSS can be applied to construct a 3D seismic velocity structure model of the crust in this area. The velocity model can further be converted to a 3D density model using the empirical relationships that prevails between the seismic velocities and mass densities. Structural effects of the crust can then be estimated, results obtained are shown.

DEPTH DISTRIBUTION OF CRUSTAL AEROMAGNETIC AND GRAVITY ANOMALIES

G. Kletetschka and J. H. Stout (U of M, 310 Pills Dr SE,55108,Minneapolis,USA)

The distribution of deep crustal sources of aeromagnetic and gravity anomalies can be obtained by assuming a different variance of sources within the anomaly than in surrounding areas. The amplitudes of the small scale variation in an anomaly differs from the variation of the signal outside the anomaly. Variation in high frequency amplitudes across a large scale anomaly can be detected by finding the envelope of the high frequency signal. High frequencies are assumed to be generated only by near surface sources. Inversion of the envelope of the high frequency signal detects the low frequency anomalies of the surface sources as well. By integrating both the low frequency signal from the inverted envelope and the original high frequency signal we can effectively separate the signal generated exclusively by surface sources and use it for mapping the density and/or magnetization of the uppermost layer. The rest of the signal left after the above separation must be related to deeper geophysical sources. By further deeper source signal filtering and successive envelope applications we can generate a model of the density and/or magnetization distribution in layers at different depths below the surface.

THE INTEGRAL EQUATIONS FOR SOLUTION OF THE FORWARD D.C. GEOELECTRIC PROBLEM FOR A 3-D BODY OF INHOMOGENEOUS CONDUCTIVITY BURIED IN THE HALFSPACE

M. Hvoždara (Geophysical Institute of the SAS, Dúbravská 9, 842 28 Bratislava, Slovakia)
P. Kaikkonen (Department of Geophysics, University of Oulu, SF-90570 Oulu, Finland)

The paper presents the integral solution of the forward D.C. geoelectric problem for a 3-dimensional target body of non-uniform conductivity $\sigma_T(x, y, z)$ burried in the halfspace $z \geq 0$. The derived formulae are combination of boundary- and volume- integrals. Numerical calculations are performed for the case of a 3-D rectangular prism embedded in the halfspace while the exciting potential is due to a single point electrode on the surface of the earth. There are presented isoline and profile curves for the anomalous potential (due to the prism), for the total potential, as well as profile curves for the apparent resistivity ρ_a/ρ_1 (using 3-electrode Schlumberger array). It is shown that the presence of the 3-D prism is most expressive in profile curves of anomalous potential and apparent resistivity.

THE GEOPOTENTIAL FIELD DATA AT THE DIFFERENT ALTITUDES OVER EASTERN SIBERIA REGION AND ITS STATISTICAL ANALYSIS

A.L. Kharitonov (Institute of Terrestrial Magnetism, Ionosphere & Radiowave Propagation Moscow reg., 142092, Troitsk, Russia)
I.A. Aleschev (State Academy Oil and Gas, Moscow reg., 141570, Mendeleevo, Russia)
V.V. Stogniy (Yakutsk State University, Russia)

The aeromagnetic measurements were performed at altitudes of 0.1 km, 0.3 km, 1.0 km, 3.0 km along the aeromagnetic flight path over Aldan and Stanovoy regions. The field of magnetic anomalies at the 30 km and 400 km altitudes was measured on board of the sratospheric balloon and satellite along the aeromagnetic flight path. There are gravity data in reduction Bouger along the transsiberian profile on the Earth' surface and at satelitte altitudes. The geophysical interpretation of the geopotential data (geomagnetic, gravity, seismic, heat flow data) obtained along the transsiberian profile is considered. The results of spectral analysis of aeromagnetic, balloon and satellite measurements was presented. The statistical analisis in interpretation of gravity and geomagnetic fields is used in this paper.

A FAST SPHERICAL TRANSFORM ALGORITHM

V. Lesur (Department of Earth Sciences, University of Leeds. LEEDS LS2 9JT, U.K.)

We have evaluated the utility of an algorithm proposed by J.R. Driscoll and D.H. Healy for the forward and inverse transform of a two dimensional function $f(\theta, \phi)$ into its spherical harmonics coefficients h_l^m and g_l^m.
The forward transform consist of an FFT in the direction ϕ and a numerical integration in the θ direction. For b sampled values of the function and b coefficients to be computed at a given order m, the latter integration can be done in $O(b^2)$ multiplications with the usual Gauss-Legendre integration method. The new algorithm uses twice more sampling points and, asymptoticaly. only $O(b\log(b)^2)$ operations are needed.
However, due to numerical instabilities for large order m, this asymptotic behaviour can not be reached. The computational cost is still in $O(b^2)$. Nevertheless, for small m and large value of b the new algorithm is very efficient.
In a decomposition of a function into spherical harmonics up to a degree $lmax$, for each order m smaller than $lmax$, we have to compute $lmax - m + 1$ coefficients. In this setup, with $lmax = 512$, code runs four times faster when using this new algorithm rather than the Gauss-Legendre method. This algorithm is therefore an efficient tool for interpolation and other operations on potential field data.

GLOBAL MAGNETIC FIELD STUDIES AS PART OF THE MINI-SATELLITE MISSION CHAMP

H. Lühr, V. Haak, Ch. Reigber and P. Schwintzer (GeoForschungsZentrum Potsdam, Telegrafenberg A 17, D-14473 Potsdam, Germany)

The small-satellite mission CHAMP (Challenging Mini-Satellite Payload) is a national German project aiming at geoscientific research and application. The main responsibility both for the definition of the scientific goals and for the execution of the project is with the GeoForschungsZentrum Potsdam (GFZ). The three major research areas are the gravity field, the internal and external geomagnetic field and the atmosphere/ionosphere. CHAMP shall be launched mid-1999 into a circular, near-polar orbit of about 450 km altitude. The natural decay of the orbit will cause a termination of the mission after 5 years.
For the mapping of the geomagnetic field - on which we will concentrate here - CHAMP is equipped with a complementary set of instruments mounted on a 4 m boom. The magnetic field instrument package allows for repeated in-orbit calibrations during the emission.
For a number of examples we will point out to which research areas the magnetic field readings of the CHAMP mission can make major contributions.

PRELIMINARY GEOID MODEL FOR ARGENTINA (SOUTH AMERICA)

M. C. Pacino (Instituto de Física Rosario - CONICET - Universidad Nacional de Rosario. Av. Pellegrini 250 - 2000 - Rosario - ARGENTINA)

Argentina is working on the determination of a precision geoid model under the auspices of the National Committee of the International Union of Geodesy and Geophysics (CNUGGI) and the Sub-Commission for the Geoid in South America (SCGSA).
The computation has been based on a revised data set of gravity covering the major Argentinian territory.
Topographic and bathymetric data were used to generate a DTM in a 3' grid. The remove - restore procedure was used to get the geoid estimate.
The geoid computed has been compared to geoid undulations obtained by GPS/levelling. The final results are presented in form of a contour line map.

A STUDY OF THE CONTINENTS DRIFT

T. D. Petrova (Geophysical Institute, 1113 Sofia, Bulgaria)

In connection with an investigation of the drift of the continents, a study has been performed initiated by D. Zidarov on the basis of current loops. A suitable program was worked out and a number of theoretical experiments were made with it. For simplicity, the case of two continents was considered. The parameters of the loops are determined by minimizing the corresponding sum of squares. This study has been realized for the first time and we hope that using real data new information will be obtained concerning this drift only on the basis of magnetic data.

SOLUTION OF INVERSE NON-LINEAR 3D PROBLEM OF GRAVIMETRY FOR MEDIUMS WITH VARIABLE DENSITY-DEPTH RELATIONSHIP

Y.V.Pyatakov , V.N.Krasikov
Institute of Marine Geology & Geophysics, Yuzhno-Sakhalinsk 693002, Russia.

Mathematical formulation and iteration algorithm for solution of inverse non-linear 3D problem of gravimetry for mediums with variable density-depth relationship are presented. Effective high-speed and accurate algorithms of linear 3D problem solution are created. The created methods' effectiveness was studied on models. Methodological capabilities of detailed gravity survey for the solution of oil geology structure problems are illustrated for potential oil and gas-bearing areas of the Kamchatka Peninsula and Sakhalin Island.
Algorithms for solution of the problem of evaluation of medium tension-deformation state caused by density contrast are derived.

AN INVESTIGATION OF HOMS MAGNETIC AND GRAVITY ANOMALIES, OFFSHORE LIBYA

G.A.Reeh, and **Y.Essheh** (Petroleum Research Centre Exploration Department, P.O.Box 6431 Tripoli Libya)

The Homs magnetic and gravity anomalies is located in the central Mediterranean area between Sicily and north African coast, lies on Pelagian block stretched and thinned cratonic crust and flanked on its eastern and western margins by two deep Oceanic basins. The analysis of the power spectrum of the anomaly indicates that it results from two groups of sources; a shallow group at depth of 4.00 km and a deeper group at depth of about 9.00 km. Three-dimensional interpretation of magnetic anomaly indicate that the magnetic source has a total magnetization vector dipping at 70° azimuth 0°, with an intensity of 1.2 A/M. The poor correlation between the pseudogravity fields for induced magnetization of magnetic anomaly with the observed gravity fields strongly suggests that the causative structure has remanent magnetization. The mean temperature gradient was measured in the BINC -35A well which is located in the centre of the anomaly and show that the magnetic body controlled by the depth of the Curie isotherm. Considering the tectonic history of the area combined with the analysis and interpretation of all the geophysical data, suggests that the body of Homs anomaly may has formed during Jurassic extensional phase. The positive topographic region over the causative body was not caused by the intrusion of igneous body, it is probably represents a residual high due to the subsidence of the Jarrafa basin to the north and the Sabaratah basin to the south. The igneous body responsible for the stabilization of this region since the time of intrusion.

The Geopotential and Atmospheric Research Mission CHAMP

Ch. Reigber (GeoForschungsZentrum Potsdam, Telegrafenberg A 17, D- 14473 Potsdam, Germany)

The Small Satellite CHAMP is an approved mission in Germany's national space program. The CHAMP project is managed by GFZ and the satellite is built by the German space industry. Payload contribution partners are NASA (GPS-receiver), CNES (accelerometer) and Phillips Laboratory (Ion drift meter).
Champ shall be launched into a 450 km altitude near polar orbit and shall decay during its five years lifetime to about 300 km altitude. During this mission period the onboard instruments will collect sufficient precise data for a highly improved modelling of the Earth's static gravity field and it's temporal variations as well as of the main magnetic field, the crustal and external magnetic fields. In addition GPS tracking and limb sounding data can be used for sounding the neutral atmosphere and ionosphere over a long period of time.

THE INFLUENCE OF CORE FLATTENING ON THE ROTATIONAL SPLITTING OF FREE OSCILLATIONS

Y. Rogister and C. Denis
(Institut d'Astrophysique, 5, av. de Cointe, B-4000 Liège, Belgium)
S. Tomecka Suchoń
(AGH, Institute of Geophysics, Al. Mickiewicza 30, PL-30059 Kraków, Poland)

Rotation and ellipticity split the degenerate eigenfrequencies of oscillation of a spherical, non-rotating Earth model. Anomalous splittings have been observed and their origin is generally attributed to an anomalous structure of harmonic degree 2. In this work, we investigate the influence of the flattening at the core mantle boundary on the splitting parameters by comparing the structure coefficients for PREM with those of recently published Earth models. The latter are based on an inertia coefficient close to 0.332, rather than the PREM inertia coefficient 0.3308. The effect of such a slight change of inertia affects core structure rather significantly and reconciles the computed and observed flattenings without altering too much the eigenvibration periods. We present results for the splitting parameters pertaining to the new models. Preliminary results seem to indicate that the latter agree better with the observations than those computed for PREM and similar Earth models. One conclusion we draw from our study is that the density jump at the inner core boundary is very likely to be much smaller than the PREM value.

GRAVITY AND GEOMAGNETIC MAPS OF YUGOSLAVIA

Miroslav Starcevic, Aleksandar Djordjevic, Tomas Cupkovic
Mining and Geology Faculty, Djusina 7, 11000 Belgrade, YU

The Bouguer Gravity Map and Ground Magnetic Map (Vertical component) of Yugoslavia and their correlation to Geological features are presented.
Several maps more, connected to those maps, are presnted too: topography with Bouguer gravity, generalized structural map according to gravity and geomagnetic data and Moho-boundary map according to gravity data.
An representative regional geologic cross-section across Yugoslavia is interpreted.
Some possibilities of using presented geophysical data are appointed.

SNAP : ALGORITHMS FOR SYNTHESIZING THE EARTH'S GRAVITY FIELD

V.N.Strakhov, A.V.Strakhov, D.E.Teterin, I.E.Stepanova (RAS, Institute of Physics of the Earth, Bol. Gruzinskaya 10, 123810 Moscow, Russia),
U.Schäfer (Institut für Angewandte Geodäsie, Außenstelle Potsdam, Michendorfer Chaussee 23, D-14473 Potsdam, Germany)

Usually global and regional gravity models of the Earth are represented by truncated series of spherical functions. SNAP is a new analytical approximation of the gravity field proposed by V.N.Strakhov that has a few numerical advantages. Utilizing this analytical approach it will be possible to obtain approximations of potential fields with significant higher resolution than by means of currently used spherical harmonic models.
Using a SNAP coefficient set, which is assumed to be known, the synthesis of the gravitational potential $V_N(x)$ and of its spatial derivatives can be carried out with high performance. This is due to the fact, that the algorithmic formulas allow concurrent computing. Moreover, the numerical formulas are relatively simple and enormously stable in comparison to the classical recurrent formulas, which commonly applied for Legendre's functions.
In case of all the first spatial derivatives in spherical coordinates as well as in cartesian coordinates one has to determine only two types of the following sums

$$f(\tau) = \sum_{n=0}^{N} k_n \tau^n$$

with given (in general complex) coefficients k_n and complex quantities τ.
Hence, by means of the SNAP-approach the synthesis problem may be drastically simplified.

On combining ground-based and satellite field data

W. Webers (GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany)

Recording geophysical fields by the irregular global observatory net had essentially been improved by satellite observations.Since the physical content of both the data sets is different according to the different distances from the Earth's body combining the data sets has to take into account that fact.For the global internal magnetic field the different convergence behaviour of the ground-based and the satellite orbit spherical harmonic models (SHA) is used as regularizing criterion for the ill-posed inverse problem of downwardly continuing where the same convergence quality is enforced for the ground-based as for the satellite orbit SHA model with the same truncation index. The regularizing algorithm results in a log relation from the functional systems in both SHA models.

THE RECENT HORIZONTAL EARTH'S CRUST MOVEMENTS ON THE TAVAKSAI TEST GROUND (KARZHANTAU,UZBEKISTAN) IN THE CONNECTION WITH SEISMICITY

A.R.Yarmukhamedov, S.A.Irushkin (Institute of Seismology, Uzbekistan Academy of Sciences)

Different types of the earth's crust horizontal motions were observed in the geological structures of the test ground (depression,fault zone,rize) during 1978-1995.Slightly accelerated motion in the form of tensile and compressible stresses is observed in the fault zone. The tensile stress here are almost two times as much as the compressible ones.In the depression earthquakes with K>11 occur in the period of change of the tensile stresses by the compressible ones and the contrary in the zone of rize. In the fault zone connection between seismicity and change of distances between points is quite difficult. Earthquakes with K>11 occured 24 times in the period of change of the tensile stresses by the compressible ones (phase of compression) and 15 times in the period of change of the compressible stresses by the tensile ones (phase of tension).Structural differentiation of motion in connection with seismic events is outlined.

MODEL OF THE RECENT GEODYNAMIC ACTIVITY OF THE TIEN SHAN LITHOSPHERE AND CONNECTION WITH SEISMICITY

A.R.Yarmukhamedov,K.N.Abdullabekov,Kh.K.Karimov Institute of Seismology, Uzbekistan Academy of Sciences

1.The model is based on the plate-pulsative theory of the earth's development. 2.Tectonic stress accumulation is connected with the northward movement of the Indian lithospheric plate, including movement towards the Tien Shan, and with the deep geodynamic processes in the Tien Shan itself. 3.Pulsation of the geodynamic activity in layers of the consolidated crystalline foundation leads to renovation of deformations and destruction of new structures. Stress drop is realized in the form of earthquakes and new formed and renovated faults promote transfering various chemical combinations in the form of hydrothermal solutions and fluids to the upper layers of the earth's crust, forming new and renovating existing ore, oil- and gas-bearing deposits.

THE PARTICULARITES OF CENTRAL TYPE STRUCTURES IN THE PRECAMBRIEN SHIELDS

M.S.Zeigelman, N.G.Dravert
(Institute of Geophysics, Ukraine, Kiev)

In last decade in geological literature great attention is given the problem of extraction of the central type structures (CTS), their genesis and place in the structural evolution of lithosphere and the distribution of deposits. CTS of different order, dimensions and nature are reflected in the magnetic and gravimetric fields of the Ukrainian shield. The energy generation centers of the largest structures (1 order) are situated within the mantle. From this deep centers excitation transfers to more high levels, where centers of 2, 3 and so on orders take place. In this way the satellite-structures are formed. Complicated CTS-systems determine the location of high permeability lithosphere section. Some relations between the position of chambered pegmatites, titanic iron ore deposits and CTS-elements are outlined during the analysis of geophysical fields.

SOME THEORETICAL EXPERIMENTS ON THE SOLUTION OF THE INVERSE MAGNETIC PROBLEM WITH POINT SOURCES

Zh. P. Zhelev and T. D. Petrova (Geophysical Institute, 1113 Sofia, Bulgaria)

On the basis of a profound theoretical analysis, a conclusion is drawn, that for the interpretation of local and to some extent regional anomalies, it is better to use (as elementary approximating bodies) positive and negative point sources, since in this case the charges of different signs of the real source are usually away one from the other. On the basis of this idea, a computer program is worked out, and a number of theoretical experiments are made. Reasonable results, confirming the above made theoretical suggestions , are obtained.

ON THE UNIQUENESS OF THE SOLUTION OF THE INVERSE PROBLEMS WITH ELEMENTARY SOURCES

Zh. P. Zhelev (Geophysical Institute, 1113 Sofia , Bulgaria)

It is proved, that if the field of a gravity body can be represented exactly by the field of elementary sources (it can be easily shown, that the set of such bodies is not empty) , then the location of each of them must be inside (at least at the surface of) the smallest body of the family of bodies with identical exterior fields, to which this body belongs. A similar evidence probably can be made olso for the magnetic case. This proof is of importance for the solution of the inverse problems with elementary sources.

SOME RESULTS OF THE ANALYSIS OF A COMPLICATED GRAVITY ANOMALY WITH ELEMENTARY SOURCES

Zh. P. Zhelev and T. D. Petrova (Geophysical Institute, 1113 Sofia, Bulgaria)
R. Vieira and F. Gonzalez (Instituto de Astronomia y Geodesia, 28040 Madrid, Spain)

A gravimetric survey covering a site 200 m square was carried out to locate karstic cavities. After a preliminary polynomial approximation to eliminate the main part of the regional trend (so that to ease the optimization) , the local gravity anomaly together with the rest of the trend is modeled with a set of eleven point sources and a linear trend. The unknown parameters of the suggested model are determined through optimization. The results show the probable presence of a system of cavities and galleries, which seems to be in agreement with the drillings and other information about the region.

SOME RESULTS ON THE INVERSION OF SEVERAL MAGNETIC ANOMALIES WITH ELEMENTARY SOURCES

Zh. P. Zhelev and T. D. Petrova (Geophysical Institute, 1113 Sofia, Bulgaria)

A number of practical problems are settled by the method for solution of the inverse magnetic problem with positive and negative point sources, suggested and elaborated by us during the last several years. Three complicated real magnetic anomalies from the territory of South Bulgaria are analysed by it. The depths of their sources and the respective masses are approximately determined through optimization. A model of the corresponding magnetic field in the region is constructed on this basis.

SE17/G2 Determination of the high-resolution gravity field

Convener: Francis, O.
Co-Convener: Hinderer, J.

Estimation of Low Degree Geopotential Coefficients using SLR data

R. Devoti, M. Fermi, V. Luceri, P. Rutigliano,.C.Sciarretta (Nuova Telespazio SpA, Centro di Geodesia Spaziale G. Colombo, Matera, Italy)
G. Bianco (Agenzia Spaziale Italiana - Centro di Geodesia Spaziale G. Colombo, Matera, Italy)

Geodetic satellites have been providing the low frequency part of the geopotential models used for precise orbit determination purposes (e.g. JGM3, EGM96,...). Nevertheless they can be used to estimate the temporal variation of selected coefficients, helping to clarify the complex interrelations in the earth-ocean-atmosphere system. In this presentation the results from the data analysis of the main 7 geodetic satellites (Lageos1-2, Stella, Starlette, Ajisai, Etalon1-2) are discussed, obtained separately and in proper combination, to recover monthly estimates of low degree geopotential coefficients. The accurate modelling of the satellite orbits is required in order to separate those coefficients: we assume as a-priori geopotential the JGM3 model together with its associated tides and we take care of non-gravitational effects on the satellites by means of proper empirical estimated accelerations. The time series of the estimated coefficients (J2, J3, J4, J5) will be inspected to detect the sub-annual perturbations related to seasonal variation of mass distribution.

ASTROGEOID VERSUS GRAVIMETRIC GEOID

Gottfried Gerstbach (Institute of Geodesy and Geophysics, TU Vienna, Gusshausstr. 27-29/128, A-1040 Wien, Österreich.

European projects in hilly and alpine regions show that astro-geoid solutions are more effective than gravimetry. Geoids of ±2-5cm require 5-15 astro points per 1000 km², but 50-500 gravity points (projects in A, CH, D, I, GB, H, former YU). For the latter it is very laborious to cross alpine slopes in such a grid of 2km, including adequate tacheometry.

This is explained by topographic or geological density anomalies: they cause *systematic* gravity errors, but *quasi-random* effects on vertical deflections. Therefore gravimetry yields cm accuracy only in flat regions with narrow point spacings <3km (e.g. northern or eastern Germany).

Both methods are improved remarkably by subsurface density models (smoothing of the gravity field). Such models reduce astrogeoid errors by 50% even with simple inclination models (2.5D). The only serious drawback of *astro* observations (night-time, some experience needed) will be overcome within a few years by automatic CCD measurements.

Countries with sparse or secret gravimetric data should increase the vertical deflection points to distances of 10km to reach a *cm-geoid*. Even by 20km spacings (average in Europe) and *rough* geological maps or profiles the geoid can be improved to ±5cm per 100km (locally ~3cm) within a few years.

ADJUSTMENT AND QUALITY CONTROL OF A PART OF POLISH PRIMARY GRAVITY NETWORK

M.Cisak (Institute of Geodesy and Cartography, Jasna 2/4, PL-00013, Warsaw, Poland)
A.Lyszkowicz (Space Research Centre PAS, Bartycka 18A, PL-00716, Warsaw, Poland)
A.Sas-Uhrynowski (Institute of Geodesy and Cartography, Jasna 2/4, PL-00013, Warsaw, Poland)

In 1992 Warsaw-based Institute of Geodesy and Cartography has started a modernization of Polish fundamental gravity network. The new Polish precision gravity network is based on absolute free-fall measurements, and relative gravity observations using LaCoste& Romberg gravimeters. The adjustment of the part of the Polish gravity network has been done by the Lesadgra software, originally developed in Delft by G.L. Strang van Hees and Eric de Min. It was the following problems that the test aimed to consider: drift of the instruments, correlation between the observations, calibration factors of the instruments, connection to given absolute gravity points and testing for gross-errors in the observations. The results of the test adjustment indicate that a network has very high quality, with a standard deviation about 15 mGal for single observation.

A NEW FRENCH GEOID MODEL.

H. Duquenne (Ecole Supérieure des Géomètres et Topographes, 18, allée Jean Rostand, F-91025 Evry, France)
(Institut Géographique National, 2, avenue Pasteur, F-94160 Saint-Mandé, France)

A new quasi-geoid covering France is computed from a geopotential model, gravity data and a digital terrain model, using a remove-restore technique and Stokes' integration. The gravimetric solution is compared with a set of 1100 levelled GPS points, leading up to a standard deviation of the discrepancies of 0.12 m after a 3D fit. A grid to convert ellipsoidal heights into normal heights is derived. Some independent tests indicate a precision of 0.025 m in the conversion.

ɜH-PRECISION GRAVITY-MICROSEISMIC STUDIES OF FAULT NES

na V. Glukhova, Vladimir G. Budanov (VNIIGeofizika, Moscow)

ɜ fact that vibration of the foundation affects the position of the pendulum ı sensitive system of high-precision gravimeters was established back in 1960-s. Vibration-induced systematic deflections of pendulum (up to 0.1 al) are indistinguishable from real Δg. Physico-mathematical explanation he effect is suggested and the technology of laboratory investigations ıg a vibrotable is described. Gravimetric and simultaneous microseismic easurements performed at a number of continental fracture zones nsform and other classes) proved to be highly effective. It was shown ! these zones are not the whole entities but rather the sequences of bile and immobile areas. Before and during the seismic events it is the bile areas which demonstrate the increasing microseismic activity which ults in discrepancies in gravimeter readings. Since the microseismic plitude changes are practically insignificant (about several nM) and are ıin the threshold of resolution of seismic machinery, vibration-induced vity anomalies are unique highly-sensitive indicators of the level of ture zone activity.

SSIBILITIES OF HIGH-PRECISION GRAVITY STUDIES IN THE INITORING OF HYDROCARBON DEPOSITS

na V. Glukhova, Vladimir G. Budanov (VNIIGeofizika, Moscow)
dimir N. Rozenberg (Zentrgeofizika, Moscow)

ltiple gravity measurements within a month were performed in 1993-95 several known hydrocarbon deposits. It was found that during the eated high-precision (5-20 μGAL) measurements (the need in such high cision was dictated by the situation), natural microseisms (frequency: 200 Hz, amplitude: several nM) become the main source of errors. It s also established that microseism fields and microseism-induced Δg ds over the hydrocarbon deposits and outside its limits are essentially erent. The procedures of gravity-microseismic measurements allowing to ineate the position of hydrocarbon deposits correctly and to monitor it ing the period of its exploitation were developed.

During the shipboard gravity measurements in the Sea of Okhotsk, khalin shelf, and in the Black Sea, Romanian shelf (1981-1990), we ained the accuracy of 0.09-0.13 mgal in movement and 0.04-0.05 mgal ing anchor moorings. Thus, the possibility to outline hydrocarbon posits in the sea and to use shipboard measuremnets for gravimetric nitoring was opened for the first time. This cheap, non-polluting, and hly effective monitoring technique seems to have no rival at present.

HIGH-ACCURACY GRAVIMETRY FOR STUDYING THE MAJOR STRUCTURES OF THE OCEAN BOTTOM

Mikhail I.Gurevich, Igor V.Belyaev (Sevmorgeo, St-Petersburg), Vladimir G.Budanov (VNIIGeofizika, Moscow)

For dynamic gravimetry the restoration of the measured field (up to 20-30%) is necessary to avoid distortions. Without it, information about the crust density is unreliable. The approach suggested contains consideration of the crust geometry data (bathymetry and seismic data) as gravity sources. The main method for studying is the combined spectral analysis for known transfer functions of gravimeters. Most reliable local gravity anomalies data can be obtained for maximum values of coherence and phase angle. Thereafter the calculation by the *σ-block* program within the limits of 2nd layer was fulfilled for some transform faults, rift zones etc. Analysis of the gravity field fine structure showed: 1) the crust blocks with σ from 2.0 g/cm^3 (sedimental) to 3.3 g/cm^3 (mantle) are picked out within the limits of 2nd layer under the thin basalt layer, and 2) it is proved that main set of these blocks differs in σ on the western and eastern wings of Mid-Atlantic Ridge (~2.3 and 2.8 g/cm^3, respectively). For similar analysis on shelves, accuracy ~0.1 mGal was obtained, and the areas of small negative anomalies (0.3-0.5 mGal) were picked out to outline locations of hydrocarbon deposits.

GRAVITY MEASUREMENTS IN, ABOVE AND AROUND THE CHANNEL TUNNEL: AN NOVEL IMAGE OF THE VARISCAN FRONT

R G Hipkin (Department of Geology & Geophysics, Edinburgh University, EH9 3JW, UK)
J Edwards (British Geological Survey, Murchison House, West Mains Road, Edinburgh, UK)

High precision gravity measurements were made at 150 m intervals along the Channel Tunnel and then used to constrain conventional marine gravity surveys in the Dover Straits. Using a novel weighted adjustment, the RMS errors at 101 line intersections was only 0.18 mGal. The subterranean and marine data were combined with land data from England and France to produce a well-controlled Bouguer anomaly map. Euler deconvolution applied to these data provides a detailed image of Variscan faulting suggesting that the most significant features lie well to the north of the conventional position of the Variscan Front in Southern England. For example, it is concluded that the 'Lille-Dungeness Fault' does not continue as a significant structure across the Channel. The major boundary fault is taken up en echelon on a new fault through Calais and is crossed by Tunnel. Thereafter, further en echelon features transfer a large part of the Variscan deformation to the north of Kent.

MEASURING THE GRAVITATIONAL ACCELERATION USING OSCILLATIONS IN A SYSTEM WITH LEVITATED MASS.

V.M. Khavinson, E.T. Frantsuz
D. I. Mendeleyev Institute for Metrology (VNIIM), Russia

A new method is proposed for the measurement of the acceleration of gravity. The method relies upon the fact that any system which levitates a body and has a single vertical degree of freedom behaves as an oscillator with a restoring force which is proportional to weight of the body, provided that certain conditions are fulfilled.
In such a situation the equation of free small-amplitude vertical mechanical oscillations for the levitated body is isomorphic to that for a simple pendulum of length, which is determined by geometric characteristics of the system. Therefore, the frequency of free oscillations of the body about a fixed equilibrium position is independent of a value of the levitated mass, and depends only on g and on the geometric characteristics of the system in a vicinity of the equilibrium position. This allows gravitational acceleration to be determined from measurements of natural frequency and the geometric characteristics of the system. From conservative estimations it may be concluded that the main contribution to the uncertainty of the method does not exceed that of the conventional ballistic method and, perhaps, can be further reduced. This gives promise that the proposed method would be able to compete with the conventional one.
Particular features of the method and possibility of g-measurement at an uncertainty level of a few parts per billion are discussed.

Investigations in Data Weighting and Calibration for Geopotential Model Development

F. G. Lemoine, Laboratory for Terrestrial Physics NASA GSFC Greenbelt, MD 20771 USA
E. C. Pavlis, NASA GSFC & Dept. of Astronomy University of Maryland, College Park, MD 20740 USA
N. K. Pavlis, M. H. Torrence, C. M. Cox, D. C. Chinn, and S. M. Klosko Hughes STX Corp., Greenbelt, MD 20770 USA

The relative weighting of data from satellites tracked continuously by systems such as GPS and TDRSS poses significant challenges within any type of solution. In a gravity solution in particular, the selection of the weights for these data must consider the appropriateness and applicability of the calibration technique of Lerch [1991]. This calibration technique exhibits nonlinear behaviour when applied to the relative weighting of data derived from GPS or TDRSS tracking. Other criteria, such as comparison with mean 5degx5deg altimeter derived gravity anomalies or GPS leveling comparisons, as well as other methodologies must be utilized to ensure that these data do not overwhelm the solution. This paper will describe techniques which might be applied to properly incorporate these new and strong data types into satellite only gravity solutions. We will also discuss an independent calibration of these new data primarily from 1993 through 1995, with respect to the other data that contributed to the JGM2 and EGM96 gravity solutions from systems such as SLR, DORIS, Tranet, in the years prior to 1993.

A NEW GENERATION OF GRAVIMETRIC GEOID OF POLAND TO SUPPORT GPS GEODETIC APPLICATIONS

A.Lyszkowicz (Space Research Centre PAS, Bartycka 18A, PL-00716, Warsaw, Poland)

Recently Department of Planetary Geodesy produced few geoid models using software developed at the University in Calgary and in Danish National Survey and Cadastre and modified by Department to run on a PC and HP. A new geoid (GEOIDA96) is based on GRS80, uses the OSU91 geopotential model, and is gridded at about 2 x 2 km over the Poland territory. It was computed by using Fast Fourier Transform using spherical Stokes kernel, as well as the gravity and terrain remove-restore techniques. A crucial amount of new gravity data has been included in new solution and the model was improved in these areas by factor of two or three. New digital model data were added to the geoid model over various regions and this also improves it significantly.

GOCE THE PLANNED GRAVITY MISSION OF THE EUROPEAN SPACE AGENCY

Miguel Aguirre-Martinez, Johan Johannessen, A. Tobias-Galicia, European Space Agency

The European Space Agency (ESA) has being studying nine Earth Science missions within the framework called 'Earth Explorers'. They were presented at a Symposium that took place in May 1996. The scientific community chose four of them for further studies. One of the chosen for continuation is a mission to map the gravity field. The name of this mission is GOCE (Gravity field and steady-state Ocean Circulation Explorer. A range of scientific requirements for the mission has been already established. The scientific requirements are converted on mission requirements. An error analysis is performed and an allocation of key design is derived. The requirements can be fulfilled by different mission implementations. The mission elements include: the instruments, the satellite, the orbit profile, the ground segment and other ground observations. The satellite is carrying two instruments: a 3 axes gradiometer, that could be either ambient temperature of cryogenic, and a GPS GLONASS receiver. Due to its low flying altitude, a gravity measuring satellite has to deal with external angular and linear accelerations. These accelerations can be either controlled or measured. Tools that have been considered for this purpose include: ion and gas thruster for drag and attitude control and the gradiometer for lineal and angular acceleration determination. The satellite configuration and orbit profile can also be optimised for best external disturbance rejection and gravity signal recovery. The low orbit altitude produces drag decay that could or could not be compensated. Each approach generate a different final performance and mission complication. All the satellite elements interact with each other in a complex way and analysis of interaction are included. Several trade-off between mission implementations have been performed and the results are provided. They include missions: with ambient temperature or cryogenic gradiometers, with or without drag compensation, with fine attitude control or only with fine attitude knowledge. Different mission duration and orbit profiles (altitude and inclination) have been also considered. A brief description of the ground segment is also provided. The paper finishes with an analysis of the implication on the mission design of a possible requirement on gravity variation with time.

LACOSTE AND ROMBERG GRAVITY METER ERROR MODELS FOR AIRBORNE GRAVIMETRY.

A. V. Olesen and R. Forsberg (National Survey and Cadastre, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark)
A.Gidskehaug (Inst. of Solid Earth Physics, Alle'gt 41, N-5007 Bergen, Norway)

The airplane phugeoid motion is a major part of the accelerations experienced by an airborne gravity meter, and high precision positioning is required to make an adequate correction. On the other hand the same quasi-periodic motion gives an opportunity to calibrate the k-factor, the horizontal accelerometers and to control the time synchronization between the data streams by correlation analysis. A precise monitoring of the horizontal accelerations is vital for tilt corrections. The presentation will focus on the use of such an analysis and on determination of cross coupling coefficients.
Gravity results from an airborne gravity campaign in Skagerrak, located between Norway and Denmark, are presented in this context and compared with ground truth gravity. This campaign was the first test of the AGMASCO system, a combined sea-surface topography and geoid mapping tool.

COMPARISONS OF THE GEOIK, GEOSAT AND ERS SATELLITES ALTIMETRY DATA OVER SEAS AROUND RUSSIA

P.P. Medvedev (Geophysical Center, Molodezhnaya 3, 117296 Moscow, Russia, pmedv@wdcb.rssi.ru), J.R.Heirtzler (NASA Goddard Space Flight Center, Greenbelt, MD 20771; 301-286-8364, jamesh@ltpmail.gsfc.nasa.gov)

Since 1985 a number of Russian satellites, in the co-called Geoik series, carried radar altimeters. Previously classified data from of these satellites, from mid 1985 to 1995, is being transferred to the World Data Centes. The data format is similar to the Geosat standard format. Ten years of altimeters data from the Russian Geoik satellites hase been analysed over seas around Russia to estimate the mean sea surface and gravity anomalies and to compare this data to GEOSAT and ERS data. These Russian satellites were in near circular orbits at an altitude of about 1500 km. Most had an inclination of 74 degrees, but some had an inclination of 83 degrees. The altimeters operated at a frequency of 9.5 Ghz with instrument error of from 0.5 to 0.8 m for the various spacecraft. Signal processing can reduce this error. The mean sea surface and gravity anomalies are discussed. Telecommunication access to this Russian altimetry data and the future prospects are discussed also.

AGMASCO: GPS KINEMATIC POSITIONING IN AEROGRAVIMETRY

G. Xu, L. Timmen (GeoForschungsZentrum Potsdam, Div. I: Kinematics and Dynamics of the Earth, Telegrafenberg A17, D-14473 Potsdam, Germany)

Within the EU project AGMASCO (Airborne Geoid Mapping System for Coastal Oceanography) 5 European institutions are encouraged to establish an operational airborne remote sensing system for gravimetric and oceanographic applications. In this context, one main task is the development of GPS software to determine position, velocity and acceleration of the moving platform. A first test campaign was carried out in northern Germany in June 1996. The related data of static/kinematic GPS monitoring of the flights have been processed. The kinematic solution includes velocity and position. The results and evaluation analyses are shown. The inner precision of static GPS positioning using 2 to 3 hours observation in a 180 km network is better than 2 mm. The repeatability tests prove that the accuracy of the static solution is about 1 cm. For the total flight time of 6 hours the velocity in vertical component has an accuracy of about 5 mm/s.

SE18/G3 Determination of 3D crustal deformations and their geodynamic implications

Convener: Drewes, H.
Co-Convener: Blewitt, G.

CRUSTAL MOTIONS IN SOUTH-EAST ASIA OBSERVED WITH GPS

B.A.C. Ambrosius, W.J.F. Simons and R. Noomen (Delft institute for Earth Oriented Space research, TU Delft, the Netherlands), D. Angerman, P. Wilson (GFZ, Potsdam, Germany), M. Becker, P. Neumaier and E. Reinhart (IfAG, Frankfurt, Germany), C. Vigny, A. Walpersdorf (Ecole Normale Superieure, Paris, France)

In November/December 1994 and in April 1996, two large GPS measurement campaigns have been carried out, using an extensive network of stations distributed over many countries in South and South-East Asia. These activities were part of the joint EU-ASEAN GEODYSSEA' project, which addresses the complex kinematics in the region of the junction of the Eurasian, Philippine, Pacific, Caroline and Australian-Indian tectonic plates. The GPS field work was carried out by GFZ and IfAG, in cooperation with many institutes in the host countries. The measurement data have been processed by four different analysis groups, using various software packages and applying different analysis strategies. The day-to-day repeatability of the various network solutions is of the order of 3 to 5 mm for the horizontal components and 9 mm for the vertical. After removing systematic effects, the differences between the solutions of the individual groups are even smaller. Combined solutions of both campaigns have been used to derive a kinematic model for the motion of the stations. For the stations in undisturbed regions, the results are generally in good agreement with the motions predicted by global plate tectonic models, although subtle differences can be observed. This provides new information, for example, for the motion of the Sunda block relative to the rigid Eurasian plate. Also, significant new data has been obtained on the deformation processes in the Sulawesi region and in the Philippine archipelago. Finally, several 'anomalies' in the results have been related to earthquakes in the vicinity of some of the stations during the one-and-a-half year interval between the observations.

ONGOING AND RECENT DEFORMATION IN THE CENTRAL ANDES

D. Angermann, J. Klotz, G.W. Michel, Ch. Reigber, & J. Reinking (GFZ Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany)

The GFZ Potsdam established a regional GPS measurement network in the Central and Southern Andes covering parts of Chile and Argentina between 20°S and the Cape Horn. This SAGA (South American Geodynamic Activities) network includes 200 sites which had been measured first in 1993/94. In the second region of Chile (Antofagasta) and Northeast Agentina a dense part of the network was re-observed in 1995 three month after a Ms 7.3 subduction-related earthquake. In 1996, 120 sites between Arica and Pto. Mondt were re-observed. In addition to the measurements of ongoing deformation, structures indicating recent deformation were studied both in the field and using Landsat images. Aims are to compare deformation over different time scales and tectonically interprete and model the measured site velocities. The Antofagasta earthquake apparently influenced the surfaces deformation over at least 100 km normal to the trench. Dislocation models were applied in order to relate the measured velocities to standard earthquake deformation. Preliminary results suggest that the entire 1994-1995 deformation measured in the western and central part of the dense GPS traverse may be attributed to the co-seismic deformation.

FIRST RESULTS OF THE ITALIAN GPS FIDUCIAL NETWORK

Bianco G. (&), Fermi M. (*), Ferraro C. ($), Nardi A. (*), Vespe F. (&).
(&) Italian Space Agency, Space Geodesy Center, Matera, Italy - (ASI/CGS)
(*) Nuova Telespazio S.p.a., Roma, Italy
($) Nuova Telespazio S.p.a., Space Geodesy Center, Matera, Italy

Starting from 1995 new permanent GPS stations have been established in Italy to constitute the Italian Fiducial Network, together with the fundamental station in Matera. The present operational sites are: Cagliari, Matera, Medicina, Noto and Venezia, while a new station in Genova is under setup. The whole data set acquired is collected at Matera Space Geodesy Center (CGS of the Italian Space Agency) and available through Internet at the following address: geodaf.mt.asi.it. Since July 1996 the Matera ASI/CGS has become EUREF Local Analysis Center, taking part in the IGS Pilot Project for densification of the ITRF through regional GPS analysis. The ASI/CGS contribution consist of weekly solutions of 7 GPS sites coordinates: the 5 stations of the Italian Fiducial Network and 2 IGS core stations (Madrid and Wettzell). In this presentation the analyses of the data collected by the Italian Fiducial Network along the entire acquisition period will be discussed: among the major results we will describe the time-series of the stations coordinates and network baselines which will be compared with SLR and VLBI solutions.

RAINFALL AND AIR-PRESSURE INDUCED DEFORMATIONS IN A NATURAL CAVE

G. Dal Moro, M. Zadro & C. Braitenberg (Dipartimento di Scienze della Terra - Università degli Studi di Trieste, Via Weiss 1, 34127 Trieste, Italy)

Tilt and strain measurements collected in a natural cave situated in the Friuli seismic area (NE Italy) 60 m below the topographical surface are considered in the present study in order to analyse the possible correlation of the crustal deformations with respect to precipitation and barometric pressure variations. The results obtained in the past by different authors show evidence of a strong correlation with the hydrological components. These effects are ascribed to the variations of the pore pressure caused by the flow of the waters in the ground.
After the determination of the significance of the correlation, the concepts of the continuum mechanics are employed for a comprehensive description of the characteristics of the deformations associated with the considered factors. Related to the occurrence of rainfall events, we register a significative contraction of the cave with a contemporaneous rotation of the principal axes while no evident signals are revealed by the tilt components.
Regarding the areal deformation related to variations of the atmospheric pressure, the recorded amplitude (40 nstrain for a 20 mbar variation) appears minor by an order of magnitude respect to the hydrological deformation (500 nstrain for a 100 mm/day rainfall).

TYRGEONET EXTENSION TO THE NORTHWESTERN AFRICAN PLATE

M. Anzidei, F. Riguzzi and **A. Zanutta** (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143, Rome, Italy)
S. Kahlouche, S. Touam (Centre National des Techniques Spatiales, Arzew, Algeria)
N. Saadi (Institut National de Cartographie, Alger, Algeria)

The Mediterranean area is characterized by the collision between the African and the Eurasian plates at a mean rate evaluated by some authors of about 6-8 mm per year. An extension of the TYRGEONET, a regional GPS network devoted to the deformation analysis across the Italian peninsula, was recently established toward the northwestern African plate. In this poster we focus our attention on a network composed by 7 observation sites, two of them located in northern Algeria. The GPS data processing and deformation analysis procedures applied on two repeated surveys (1995 and 1996) are shown. Although the results should be considered preliminary, significant coordinate differences are exhibited by three sites.

CRUSTAL DEFORMATIONS BY GPS TECHNIQUE AND SEISMICITY IN THE IONIAN AREA

G. Casula, F. Riguzzi, S. Pondrelli, A. Zanutta and **M. Anzidei** (Istituto Nazionale di Geofisica, via di Vigna Murata 605, 00143, Rome, Italy)
P. Baldi (Università di Bologna, viale B. Pichat 8, Bologna, Italy)

A GPS network of 9 sites crossing the Ionian sea was repeatedly measured since 1991, in the frame of the TYRGEONET project. Crustal deformations were detected in 6 sites by a rigorous statistical approach analyzing the significance of the coordinate differences between four repeated surveys. The displacement field could be strongly related to the recent seismicity occurred in this area. An attempt of correlation between the moment tensor CMT solutions of the main earthquakes and the deformation style detected by the GPS technique is shown in this poster.

A NO NET ROTATION GLOBAL PLATE KINEMATIC AND REGIONAL DEFORMATION MODEL FROM GEODETIC AND GEOPHYSICAL DATA

H. Drewes (Deutsches Geodätisches Forschungsinstitut, Abt.I, Marstallplatz 8, D-80539 München, Germany)

The latest station velocity solutions from space geodetic observations (VLBI, SLR, GPS) are combined to compute an Actual Plate Kinematic Model (APKIM) comprising ten major lithospheric plates. Plate boundary zones are modelled separately as a deformable continuum by finite element and least squares interpolation methods. The kinematic datum of the model is defined by the condition of no net rotation, i.e., the integral over all motions at the Earth's surface to be zero. It is realized by the sum of interpolated velocities in a global 1° x 1° grid. Tectonic plates not occupied by at least two space geodetic stations are approximated in their motion by the geophysical model NUVEL-1A. Emphasis is laid in the interpretation of deviations between APKIM and NUVEL-1A which are obvious not only in extended plate boundary zones but also in some rigid plate rotation vectors.

THE EUROPEAN STRAIN FIELD FROM COMBINED VLBI, SLR, AND GPS DATA ANALYSIS

H. Drewes, O. Heidbach (Deutsches Geodätisches Forschungsinstitut, Abt.I, Marstallplatz 8, D-80539 München, Germany)

Some thirty European space geodetic observation stations (VLBI, SLR, GPS) are included in recent global station velocity solutions from various analysis centers. This data set forms the basis for a strain analysis over the European continent and the mediterranean orogenic belt. A finite element approach for an elastic continuum is used for modelling the deformations. Boundary conditions are introduced for the motions of the African and Arabian plates against Eurasia. They are derived from the NUVEL-1A model. The result shows extreme strain in the areas of maximum seismic risk (Hellenic Arc, North Anatolian Fault). One of these zones, the West Hellenic Arc, is modelled in detail using GPS data of the WHAT A CAT project. The result is interpreted with respect to geodynamic features in this region.

DETERMINATION OF SITE DISPLACEMENTS IN A GPS CONTROL NETWORK OF THE LOWER RHENISH EMBAYMENT

B. Görres (Geod. Inst. Uni Bonn, Nußallee 17, 53115 Bonn, Germany)

At the University of Bonn an interdisciplinary geodynamics project has been initiated in 1991 to study the complex processes associated with the transport of matter between the atmosphere and the ground including its subsurface layers. The area under investigation is the Lower Rhenish Embayment, a zone both known for its present-day seismo-tectonic activity and its extensive brown coal mining . One section of the project is concerned with the determination of site displacem ents with GPS. A series of annual GPS-campaigns covering 13 simultaneously observed p oints has been started in 1993. The size of the GPS network HEIKO is about 100 km x 10 0 km. Apart from taking into account troposperic refraction and phase center variatio ns it is important to extend the observation sessions to at least 24 hours and use low elevation observations in order to improve the accuracy (repeatability) of the height component. Extensive tests show that the best repeatabilities are obt ained when using an elevation cutoff of about 10 °. At three points of the network significant ground water induced height changes o f up to 24 mm/year were detected. Comparison with levelling results for identical sta tions lead to good agreement. In terms of wrms repeatability the results are at the level of 2-3 mm in the hei ght component on distances of up to 100 km, which is superior to the levelling accur acy. The conclusion points to an increasing importance of GPS for the determination o f site displacements not only in the horizontal components but also in the vertica l direction.

ELASTIC–ANISOTROPIC MODEL OF THE KOLA SUPERDEEP BOREHOLE (KSD–3) SECTION.

F.F.Gorbatsevich, V.L.Il'chenko (Geological Institute of KSC, Apatity, Russia).

Elastic–anisotropic properties of core and the results of inclinometric observations in the KSD – 3 borehole have been analysed and elastic – anisotropic model of the KSD borehole log has been constructed. Analysis of elastic–anisotropic properties of rocks showed the presence of 10 structural floors in the borehole section. Bedding elements for each floor have been corrected according to inclinometric data. Correction was based on assumption that a borer tends to be normal to the anisotropic (e. g. bedding) plane of the rocks. Inclinometric data for the lower part of the borehole's hole 1 is in complete agreement with the similar data obtained for holes 2 and 3.

Thus, it is revealed that in the range of 8600 to 10200 m there is a change in orientation of bedding elements of rocks to the opposite one. This statement contradicts the existing model of geological structure of the Archean part of the Kola superdeep borehole section.

INTERPRETATION OF SITE POSITION VARIATIONS FROM THE SWEDISH AND FINNISH PERMANENT GPS NETWORKS

J.M. Johansson, H.-G. Scherneck (Onsala Space Observatory, Chalmers University of Technology, S-439 00 Onsala, Sweden)
J.L. Davis (Harvard-Smithonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, U.S.A.)
M.J. Poutanen, M. Vermeer (Finnish Geodetic Institute, Geodeetinrinne 2, FIN-02430 Masala, Finland)

Project BIFROST (Baseline Inferences for Fennoscandian Rebound Observations, Sea level, and Tectonics) uses permanent GPS networks in Fennoscandia to determine the three-dimensional velocities associated with glacial isostatic adjustment (GIA). In this presentation we will discuss results obtained from the permanent GPS networks in both Sweden (SWEPOS) and Finland (FinnNet). We will assess the effects of the known sources of error, and estimate power spectra (including cross-power from the time series of three-dimensional position estimates. Using the information from these studies, we will assess the uncertainties in the estimates of three-dimsional velocity obtained from the GPS networks. We will then use these estinates to infer parameters associated with the GIA phenomenon.

COMPUTER MODELLING OF A MOUNTAIN RIDGE MOTION

N.A.Lavrov, E.E.Pavlovskaya
Institute for Problems of Mechanical Engineering of Russian Academy of Sciences

Mountain ridge is simulated by a rod-like deformable solid body embedded in an elastic half-space near the free boundary. The ridge motion is caused by the seismic impulse. Numerical solution (FEM, BEM, FDM) of dynamic 3D problem stated is connected with the principal difficulty caused by the degeneration of the region. To overcome this obstacle the proper asymptotic approach is proposed. The boundary integral equations of motion are derived on the basis of the approach proposed and are suitable for the numerical solution. The ridge curvilinear axis is assumed to be sufficiently smooth. The ridge profile is arbitrary. The cross-section shape is assumed to vary slightly along the axis (over the interval comparable with the transversal size of the ridge). 3D crustal deformations are calculated numerically at given seismic impulse.

GEOPHYSICAL INTERPRETATION OF DEFORMATIONS WITHIN EURASIA AS OBSERVED BY SPACE GEODESY

J. J. P. Loohuis (Vening Meinesz Research School of Geodynamics, Department of Theoretical Geophysics, University of Utrecht, Utrecht, The Netherlands)
R. Noomen (Vening Meinesz Research School of Geodynamics, Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands)

This paper addresses the extent of internal deformation within the Eurasian continent. The study is based on a mixture of Satellite Laser Range (SLR) and Global Positioning System (GPS) observations. The SLR observations of LAGEOS-1 and LAGEOS-2 were acquired by a global network of tracking stations and together cover the period 1983-1993. The GPS observations cover the interval 1993-1996, and were taken by a relatively dense network of stations located in Europe and directly surrounding areas. The space geodetic observations were used to compute a series of independent solutions for the coordinates of the tracking network, which were next converted into a model with epoch positions and velocities for each individual station.
The geodetic data sets have been geophysically interpreted in two ways. Firstly, a pole for rigid block motion of Central Europe has been determined. The results are compared with existing models for the motion of Eurasia, such as NUVEL-1A. Secondly, the deviations from rigid block motion have been investigated. The residual velocities have been expressed in the form of a strain rate map.

NUMERICAL MODELING OF THE PRESENT CRUSTAL DEFORMATION PATTTERN IN THE CENTRAL-EASTERN MEDITERRANEAN REGION.

Mantovani E., Albarello D., Viti M., Tamburelli C., Babbucci D.
Dept. of Earth Sciences, Univ. of Siena, Italy.

The main features of the recent/present strain and displacement fields in the central-eastern Mediterranean region, derived from geological, seismological and geodetic observations, are tentatively reproduced by numerical modeling using 2-D finite elements in a plane stresses approximation. The Mediterranean system is modeled as a mosaic of poorly deformable zones, separated by more deformable belts where deformation concentrates. In the numerical model the distribution and features of weak elastic orthotropic elements try to reproduce the compressional, tensional and transcurrent discontinuities indicated by seismotectonic studies. The system is stressed by kinematic boundary conditions simulating the motions of Africa and Arabia with respect to Eurasia. The 3-D structural features of the study area are tentatively taken into account by an opportune parametrization of the model. The results obtained indicate that this approach allows a satisfactory fit of the strain field in the zone considered, and, in particular, it can account for the occurrence of tensional deformations in some key zones (as the Sicily channel, Tyrrhenian basin, Corinth channel, Struma zone) in the framework of an overall compressional regione. A good fit is also obtained for the displacement field suggested by geodetic observations (SLR,GPS) in the eastern Anatolian and Adriatic-Apenninic system whereas some difficulties are encountered to fit geodetic data in the Hellenic Arc. The possible causes of these discrepancies are discussed

INTERNATIONAL RADIO INTERFEROMETRIC SURVEYING - SOUTH: DETECTIO N OF REGIONAL TECTONIC ACTIVITY IN SOUTHERN AFRICA

A. Nothnagel, R. Haas (both at Geodetic Institute of the University of Bonn (GIUB), Nußallee 17, 53115 Bonn, Germany)
C.J.H. Hartnady (Department of Geological Sciences, University of Cape Town, Private Bag, Rondebosch, 7700 South Africa)
G. Nicolson (Hartebeesthoek Radio Astronomy Observatory, PO Box 443, Krugersdorp, 1740 South Africa)

Since December 1989 the IRIS-S network (International Radio Interferometric Surveying - South) has been scheduled in monthly intervals. After several changes in the network configuration the standard IRIS-S network consists of four stations today, i.e. Westford Observatory (Massachusetts, USA), Wettzell Geodetic Fundamental Station (Bavaria, Federal Republic of Germany), Hartebeesthoek Radio Astronomy Observatory (South Africa) and the station of Fortaleza in Brazil which adds a fourth station on a fourth continent. The variations in the baseline length results and the station displacement vecto rs of Wettzell, Westford and Fortaleza from this data set agree very well with predict ions from current plate motion models such as NUVEL-1A. The telescope at Hartebeesthoek, however, displays movements which deviate from the model by about a few millimeters per year and a few degrees in direction. These discrepancies may be best explained by crustal motion (? microplate kinema tics) within the wide Nubian-Somalian plate boundary zone in southern Africa.

Satellite Laser Ranging Observations of 3D Geodynamics

D. E. Smith and R. Kolenkiewicz (Laboratory for Terrestrial Physics, NASA/GSFC Code 920, Greenbelt, MD 20771, USA)
E. C. Pavlis (Dept. of Astronomy, Univ. of Maryland and Laboratory for Terrestrial Physics, NASA/GSFC Code 920, Greenbelt, MD 20771, USA)
M. H. Torrence and P. J. Dunn (Hughes STX Corp., 7701 Greenbelt Rd., Greenbelt, MD 20770, USA)

We describe an analysis method which directly determines station locations and velocities in three dimensions using observations of the LAGEOS constellation. Earth orientation parameters defined by the IERS conventions provide the connection to an inertial frame, and application of a minimum constraint to a pair of well-determined tracking sites at Greenbelt, Maryland and Maui, Hawaii establishes the terrestrial frame. Geophysical interpretation of the site velocities is restricted to horizontal components for tectonic plate motion studies, as the prevailing models have been developed within a 2D system. We compare the SLR-derived horizontal velocity model with current knowledge of tectonic plate motion and crustal deformation in boundary zones in Europe, North America, South America, and Japan. The influence of vertical motion on these interpretations are discussed, and the height variations at each station summarized. Contributions to the vertical motion include the Earth's tidal response to the sun and the moon, atmospheric pressure loading, and ocean tidal loading. The geocenter motion, the three dimensional signal common to each site, provides a measure of total mass balance which is of interest in studies of global change.

COMPARISON BETWEEN GEODETIC AND GEOPHYSIC MEASUREMENTS IN THE GEMONA AREA (FRIULI, ITALY)

A. Marchesini (via Donadoni 27, I-34141-Trieste, Italy)

In the epicentral area of the Friuli 1976 earthquake a geodetic network, covering an area of approx. 10 X 10 km, was installed in 1989 to monitor the ground movements. Until 1995 a tens of Italian and German scientific institutions carried out many times various types of measurements: distance, geometric levelling, GPS, gravimetry; also a tilt meter station was active in this period. A methodology to correlate all measured data each other and with geologic constraints is proposed. All types of data get together to describe a drift inversion in 1991, the ground movements are referred to the up to now geodynamic knowledge's. The proposed methodology would be applied in other similar geodetic nets.

MODELING OF TECHNIC MOVEMENTS IN CENTRIAL ASIA WITH CONSTRAINTS OF SLIP RATES OF THE MAJOR FAULTS AND MAXIMUN HORIZONTAL STRESS ORIENTATION

Ruizhi Chen, The Finnish Geodetic Institute Geodeetinrinne 2 , 02430, MASALA, FINLAND

Tectonic movements in the region of Central Asia has been modeled with the constraints of slip rates of the major fault segments in the region and the maximum horizontal stress orientations from the global model. In stead of using the Monte Carlo method, the inversion problem was solved with a Bayesian estimator in order to take the priori information of the parameters into account in the solution. The operator which maps the parameter space to the observation space was approximated by Finite Element Method as it was not possible to expand the observation function into a Tailor series. The "split node" technique was employed for introducing the fault parameters in Finite Element Method. The inverted deformation pattern indicated that the regional component dominate the main part of the deformations. The convergence along the arc of Himalayas and the eastward extrusion of the Tibetan block absorbed the main part of the northward push of the Indian plate. The clockwise rotation of the Tarim block in relative to the Siberia is also clearly visible from the deduced model.

PLATE MOTION AND CRUSTAL DEFORMATION ESTIMATED WITH GEODETIC DATA FROM DORIS

L. Soudarin, J.F. Cretaux, F. Bouille and A. Cazenave (Groupe de Recherche de Geodesie Spatiale / CNES, 18 av. E. Belin, 31401 Toulouse Cedex 4, France)
C. Lima (Petrobas Research Center / Cenpes, Ilha do Fundao Q-7, Cid. Universitaria, 21949-900 Rio de Janeiro, Brazil)

The Groupe de Recherche de Geodesie Spatiale is involved in DORIS data analysis for the 3 satellites SPOT2, SPOT3, and TOPEX/POSEIDON and determines DORIS beacons positions and velocities using a dynamical approach. Recent improvements brought to the analyses (use of the JGM3 geopotential model, the FES-95 ocean tide model...) allowed us to reach a positioning precision at the subcentimeter level for the three components. We present here a new 3D velocity solution based on the improved processing of DORIS data collected between 1994 and 1996. Interplate velocities show a good agreement with the global plate motion model NUVEL-1A. Angular velocities describing motions between seven plates were estimated.
Intraplate deformations can be observed. In particular, results concerning the South America plate indicate that most of the compression due to the subducting Nazca plate is absorbed by the Andes and that shortening is also occuring in a midplate setting.
The motion of the sites in plate boudary zones will be discussed too.

CRUSTAL DEFORMATIONS ALONG THE PLATE BOUNDARY IN NORTHERN ICELAND BETWEEN 1987 AND 1995

C.Völksen and G. Seeber (Institut für Erdmessung, University of Hannover, Schneiderberg 50, D-30167 Hannover, Germany)
G.R. Foulger (Dept. of Geological Sciences, University of Durham, Science Lab., South Road, Durham DH1 3LE, UK)

Geodetic measurements with the Global Positioning System (GPS) were performed in Northern Iceland between 1987 and 1995 in four consecutive campaigns. The major goal was to monitor the crustal deformations following the massive dike-intrusion episode which occurred between 1975 and 1985 in the Krafla volcanic system. Up to 8m of rift normal surface widening occurred along a 80-90 km long section. The Krafla volcanic system is located in the Northern Neovolcanic Zone of Iceland which is the subaerially exposed spreading plate boundary between the North American and Eurasian plates. The deformation analysis of the consecutive GPS surveys reveal the post-rifting motion caused by the Krafla event in Northern Iceland. A maximum annual expansion rate of 4.3 cm was determined from the 1987 and 1990 surveys, while comparisons of the results from 1987 and 1992 indicate an average spreading rate of only 3.3 cm. The comparison with the 1995 data shows a further decrease in the spreading rate. In 1993 a geodetic reference network for Iceland was established. Many of these stations are identical with our points. During 1995 our network was expanded westwards so that the network stretches form the East coast to the West Coast of Iceland. The deformation analysis of the 1993 and 1995 solutions displays a half spreading rate of approximately 2 cm/a which is twice the NUVEL rate.

THREE-DIMENSIONAL NUMERICAL MODELING OF THE DEFORMATION FIELD AT MT. ETNA VOLCANO, SICILY, CONSTRAINED WITH SAR INTERFEROMETRY

C. A. Williams and G. Wadge (ESSC, The University of Reading, Whiteknights, Reading, RG6 6AB, UK)
J. G. Morley, J.-P. Muller and M. Upton (Dept. of Photogrammetry and Surveying, University College London, Gower Street, London, WC1E 6BT, UK)
J. B. Murray (Dept. of Earth Sciences, The Open University, Walton Hall, Milton Keynes, MK6 7AA, UK)

We use a three-dimensional elastic finite element model to examine the deformation field in the vicinity of Mt. Etna volcano in Sicily, and compare the results to those obtained from SAR interferometry. The finite element model includes a magma chamber, the coupled effects of surface topography and gravity, N-S regional tectonic compression, and different materials, including both stratified materials and features such as the dense volcanic plug to the southeast of the central dome. The model also includes a large decollement that intersects the surface near the volcano summit, and extends to the southeast beneath the Valle del Bove. The results are compared to interferograms obtained from passes of ERS1 and ERS2 during the summers of 1995 and 1996. Interferometric fringes and phase-unwrapped results are both computed in WGS84 ellipsoid coordinates for comparison to the finite element results. Although the surface deformation is controlled largely by inflation or deflation of the magma chamber, the near-field deformation is also strongly influenced by lava emplacement, and regional tectonic compression may affect the far-field deformation.

GPS OBSERVATIONS OF THE TECTONIC ACTIVITY IN THE TRIPLE JUNCTION AREA IN INDONESIA

ANDREA WALPERSDORF, (Dept. T.A.O., E.N.S., 24, rue Lhomond, 75231 Paris 05, France)

The point of convergence of three major tectonic plates (the Eurasian, the Philippine and the Australian plate) is situated in Indonesia. The relative plate velocities are estimated by NUVEL1 to 7 to 8 cm/yr. The complex tectonic mechanism of the triple junction has been observed during a two years time span on the GEODYSSEA network including some densification points and on a local subnetwork.
The GEODYSSEA station TOMI situated in the triple junction area has been displaced between the two main observation periods by a $M_w = 7.8$ earthquake. The non-seismic velocity will be reconstructed after the remeasurement of a local subnetwork and will be included in the modelling of a rigid block rotation in the contact zone between the Eurasian and the Philippine plate. This model is constrained by observations on the main fault system on the limit of the rotating block, the Palu-Koro fault. Previous studies predict left lateral movements of up to of 5 cm/yr. The GPS measurements on a transect across this fault show a present day left lateral displacement of 3 cm/yr.
The observations on the intermediate stations will help constrain the localisation of the deformation and the locking depth of the main fault. Geomorphological observations show clear traces of active opening in the Palu fault zone. The GPS measurements will be able to confirm if the opening corresponds to the present day activity of the fault.

SE21/G16 Local, regional and global relations of gravity with other geological and geophysical fields

Convener: Regenauer-Lieb, K.
Co-Conveners: Schmidt, P.; Seidler, E.

ABOUT THE CORRELATION BETWEEN THE GLOBAL MAGNETIC AND GRAVITY FIELDS

N.V. Alakhverdova (Sternberg State Astronomical Institute, Universitetskij pr. 13, 119899, Moscow, Russia)

The problem of the search of the correlative dependence between the global magnetic and global gravity fields anomalies is investigated. This dependence should be present if the anomalous magnetic and gravity fields have common sources laying in the outer Earth's core. The formulas for the magnetic and gravity potentials of such sources were obtained. Also were theoretically considered and calculated on the basis of the real models of the Earth magnetic and gravity fields following variants of the different types of the magnetic and gravity potentials: 1) magnetic and gravity potentials are generated by homogeneously magnetized body with different directions of magnetization; 2) magnetic and gravity potentials are generated by sources, situated on spherical surface, having different orientation of magnetic moment. The principal conclusion, made at the current stage of the investigation, is: the correlation between the magnetic and gravity fields may be discovered only in the case, if magnetization of all sources has the same direction. As the actual sources don't submit to this condition the method of searching for common sources of magnetic and gravity fields laying in the common axis have been worked out. The method is tested, using the concrete models of the Earth magnetic and the gravity fields, based on the observation data.

Gravitational interactions of the Earth's nonspherical covers and some geodynamical consequences

Yu.V.Barkin (Astronomical Institute, MSU, Univ. pr-t, 13, 119899, Moscow)

The Earth's covers form the body with dynamical symmetry about its rotation axis, but every from covers have not this property. It means that Earth's covers are dynamically-unbalance and this property is one from main causes of their relative motions and, in particular, of plate motion. Gravitational interaction of the covers having asymmetrical density distribution is permanent perturbating factor which defines together with other interactions evolution of the Earth's subsistems. In given paper the first investigations of the global interactions of the Earth's covers and possible geodynamical consequenses and effects are discused. 1) Full development of the force function of the newtonian interaction of the two nonspherical covers have been obtained. 2) The axial and centrifugal moments of inertia for models of the main Earth's covers , the coordinates of their mass centers and coefficients of the first and second harmonic of their gravitational potential have been calculated on the basis of the Earth model PREM and data about structure of the cover's surfaces. 3) The stationary motions of the mutually-gravitating ellipsoidal rigid core (RC), liquid core and nonspherical rigid mantle were studied. 4) The effect of the constant displacement of the Earth's RC on 5-10 km relatively geocenter to direction North Atlantic due to gravitational influence of the nonhomogenities of the MCB was predicted. 5) Gravity center of these inhomogeneities, probably, corresponds to magnetic center of the Earth and their attraction influence on the structure of the flows in the liquid core. 6) The interactions of the covers and influence of the inertia forces and attraction of the Moon and Sun define their relative motions, plate motion and Earth's evolution.

Instrumental confirmation and using induced seismic events increments of readings for different type gravimeters

Andrey B.Beklemishev,Vladimir G.Budanov,Oleg A.Potapov
VNIIGeofizika,Moscow,Russia

There is multitude of observations:readings of gravimeter subjected to dynamic seismic events are modified,occasionally significantly.It can be adequately understood by structural-dynamic concept originated by adepts of California Institute of Technology.Broadband and polycomponent seismic impact,characteristic for platform's margin and/or nonconsolidated localities,on gravimeter's base causes specific reaction of the concrete instrument.As a result the readings of a locked on and combined at common point different type precision gravimeters(for instance types GNU-KY,Russia;CG 3,Canada)have a tendency do not match (up to 10^{-1} mGal).Vice-versa"colored",i.e.narrowband and polarized seismic excitation,characteristic for platform's stable and consolidated localities and reaction of gravimeters pick-ups do not match in general.Therefore there is not a good chance for induced reaction.Readings has here a tendency to match.Moreover approach,named polystructural,is useful for quick discovery of faults in sediments and basement within and near the edge of platform.

GRAVITY FIELD AND ITS RELATIONSHIP TO THE CRUSTAL AND LITHOSPHERIC STRUCTURE IN THE CARPATHIAN PANNONIAN REGION

M. Bielik (Geophysical Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic)
V. Mocanu (Department of Geophysics, University of Bucharest, Traian Via Street 6, Bucharest, Romania)
A. Ádám (Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, H-9401 Sopron, Hungary)

Crustal and asthenospheric structure of the Western Carpathians, the Eastern Carpathians and the Békes Basin in the Pannonian Basin is studied by means of the interpretation of gravity field. For this study, 2D density models crossing these regions are presented. Lithospheric density models were constrained by existing geophysical (e.g. seismic, magnetotelluric and geothermal) observations, geological data and topography. Interpretations of gravity field also use density modelling in local isostasy. The models relatively long-wavelength gravity anomalies are simplified into elements representing major density contrasts (topography, Tertiary sediments, Moho discontinuity and lithosphere/asthenosphere boundary. These density contrasts are relative to typical crustal materials. Structural interpretation of long-wavelength gravity anomalies reveals crustal and lithospheric extension in the Békes Basin and mode of subduction of the European continental crust beneath the Carpathian arc. The results of density modelling indicate that geophysical, geological and geodetical data are compactible with gravity data.

STRUCTURE OF THE TECTONOSPHERE OF THE BOUVET TRIPLE JUNCTION (SOUTH ATLANTIC) BASED ON GRAVITY AND MAGNETIC DATA

E. Bonatti, M. Ligi, N. Zetellini (Instituto Di Geologia Marina, Via Gobetti 101, 1-40129 Bologna, Italy)
A. Bulychev, D. Gilod, E. Mazo, E. Kulikov, R. Zaltsman (Lomonosov MSU, Geology Faculty, Geophysical Department, 119899, Moscow, Russia)
A. Schreider (Shirshov Institute of Oceanology, Moscow, Russia)

The new charts of gravity and magnetic anomalies are prepared on base of detailed shipboard magnetic and gravity measurements for area of Bouvet triple junction (expedition of 1994y. on board of RV "Academic N. Strakhov"). These data and altimetry data were used for establishing of magnetic and gravity inhomogenity on base of 3-D inversion of potential fields. The new chronological chart was constructed for area of investigations. The neovolcanic zones were established along axis of spreading, and analysis of spreading regime was done. It was found the unstability of triple junction point in last some million years. 3-D density model of tectonosphere was constructed on gravity and satellite altimetry data for this region. It demonstrates very complex character of American, African and Antarctic junction.

EXPERIMENTAL INVESTIGATIONS ON THERMAL CONVECTION IN SPHERICAL SHELLS WITH RESPECT ON GEOPHYSICAL PROBLEMS

Claudia Böhm. Christoph Egbers and Hans J. Rath (ZARM. Center of Applied Space Technology and Microgravity, University of Bremen, Am Fallturm. 28359 Bremen, Germany)

Thermal convection in a gap between two concentric spherical shells represents an important model in geophysics. Convection in the outer liquid core generates the earth's magnetic field and perhaps influences the reversals of the magnetic pole. Investigations in wide gaps are of interest to realize this problem, whereas convection in narrow gaps can describe the motions in the atmosphere of big planets. An experimental set-up was performed to investigate the problem for different gap-sizes, temperature-differences, Prandtl numbers and Reynolds numbers. First experiments were carried out on thermal convection under an axial force field with and without rotation of the inner sphere by heating the inner sphere uniformly from within. A wide range of Rayleigh numbers and aspect ratios was investigated mainly by flow visualization studies. The instabilities occurring depend strongly on these parameters. the results are summarized in a stability diagram. Steady thermal rolls (banana type cells) and time-dependent vortices were found. The experiments allow a direct comparison between the experimental and numerical investigation and therefore serve as a check for further numerical predictions. which will include even the Lorentz forces in the Earth's core.

A FINITE-VOLUME AND AZIMUTHAL SPECTRAL 3D-SIMULATION OF THERMAL CONVECTI ON IN A ROTATING SPHERICAL SHELL

W. Brasch , C. Egbers and H. J. Rath (Center of Applied Space Technologie and Microgravity (ZARM), University of Bremen, Am Fallturm, D-28359 Bremen)

!! - The understanding of thermal convection under a central force field is important for large scale geophysical motions. The rotating spherical shell with a radius ratio of $\eta = \frac{r_i}{r_o} = 0.34$ is a model for the convection in the outer earth's core. We investigate the pattern formation of the convection in the spherical shell wi th a Prandtl number of $Pr = 0.1$ to 10 and a Taylor number $Ta > 1$. We don't consider the magnetc field here but the goal is a fast solver for the N avier-Stokes equations and the equations for the hydromagnetic dynamo. The axialsymmetric flow is calculated on a non-staggered grid with a finite volu me method. A flux is interpolated at the vertices of the finite areas to avoid the checker- board oscillations. The conjugate-gradient method accelerate the approximation. In azimuthal direction a spectral analysis allows a threedimensional simulation for spherical shells with a great radius ratio. ———

THREE LAYER EARTH'S CRUST APPROXIMATION IN TOPOGRAPHIC REDUCTIONS: A THEORY AND PRACTICE

M. Brkic
T. Basic (Faculty of Geodesy, Kaciceva 26, 10000 Zagreb, Croatia)

From Earth's crust masses, described by density and volume physical quantities, one can derive terrain effects such as anomalous gravity potential and its spatial derivatives. These can be expressed as linear functionals applied on anomalous potential - gravity anomaly, deflections of the vertical and height anomaly - and used in gravity field modelling for geodetic and geophysical purposes. More realistic spatial density distribution insures more fit Earth's gravity field model. Inclusion of three subsurface layers in description of Earth's crust masses leads to redefinition of the simple "old" topographic reductions such as topographic, topo-isostatic, terrain correction and residual terrain modelling used in well-known Forsberg's TC program. In this paper the theoretical background as well as several practical results in special area of Croatia, which have been found of the highest interest not only for geoscientists but for the state oil industry as well, will be presented.

EXAMINATION OF THE GEOID AND QUASIGEOID ALONG THE FIRST ORDER LEVELLING LINE

K. Czarnecki, M.Barlik, S. Margański, A. Pachuta, J. Walo
(Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology, Pl. Politechniki 1, 00-661 Warszawa, Poland)

The results of experimental GPS and gravimetric measurements along 70 kilometers-long first order levelling line are reported. The line runs on the foot of the Carpatians, South of Poland in the hilly area of a very complex tectonic structure. Comparison of the normal and orthometric heights was done. Geoid undulations above WGS-84 ellipsoid are presented. Analysis of geoid and quasigeoid profiles led to the conclusion that the differences of the normal heights may be considered as equal to the differences of orthometric heights in the most of practical cases.

ISOSTATIC RESPONSE OF SOME BATHYMETRIC FEATURES IN THE ATLANTIC OCEAN. A SPECTRAL ANALYSIS APPROACH

Alexandra Afonso Dias and J.M. Miranda
Centro de Geofisica da Universidade de Lisboa, R. Escola Politécnica, 58, 1250 Lisboa

Three zones of the Atlantic Ocean, named the Gorringe Bank, the Ampere seamount and the Tagus Abyssal Plain, were studied in order to separate and describe possible differences in isostatic compensation.
A new gravity compilation over West Iberian Margin has been made recently, and together with bathymetry and TOPEX-ERS1 data, it was possible to perform the spectral analysis of the gravity (and geoide) and for the bathymetric series as a function of wavelength in the perspective of simple compensation mechanisms. Results show significant differences for the three regions.
We conclude that although Gorringe Bank is not isostatically compensated the Tagus Abyssal Plain is locally compensated and the Ampere seamount shows evidence for a regional compensation scheme based on a elastic flexure model.

GRAVITY MODELLING OF CRUSTAL THICKNESSES AND STRUCTURES IN CRYSTALLINE BASEMENT

M. El Eraki* and R. O. Greiling (Geologisch-Palaeontologisches Institut, Im Neuenheimer Feld 234. 69120 Heidelberg, Germany. * on leave from Geology Dept., Zagazig Univ., Egypt).

Our modelling is based on the integration of gravity data, DSS velocity and surface geological information along three sections (Um Had, Meatiq and El Sibai, between the Red Sea and Nile River) across the Neoproterozoic, crystalline basement in the Central Eastern Desert of Egypt.
Based on the discrepancy between the observed and the computed gravity the starting crustal models were modified. In the final models, the surface geological information along each section and variations of both Conrad and Moho depths are taken into consideration, leading to the following results:
1- The eastern parts of the sections, close to the Red Sea are characterized by a thin crust, interpreted as a transition between Red Sea oceanic and continental crust.
2- From there, the Conrad depth increases from 12 km to 21 km in the west and the Moho depth from 20 km to 33 km.
3- The gravity low at El Sibai, can be attributed to a low density granitoid body (2.55 g/cm3). This body shows a maximum depth of about 4.2 km.
4- According to Moho topography and density and depth of the granitoid intrusion it is argued that the granitoid batholith lacks isostatic compensation and is genetically related to the El Sibai metamorphic core complex.

ISOSTATIC STATE OF THE CARPATHIAN MOUNTAIN BELT AND ITS RELATION WITH DEEP BUILDING

E.M. Evseeva (State University "Lviv Polytechnic", S.Bandera St.12, 290646 Lviv, Ukraine)

The valuations of isostatic state of the Carpatian Mountain Belt and neighbouring terrytories on the existent gravity information are executed. More detailed ones obtained for East Carpathian terrytory. Here the isostatic reduced geoid undulations, several isostatic anomalies and plumb line deviations with isostatic reduction are used. The relations of isostatic reduced geoid undulations with most deep geotectonic structures have discovered. The isostatic anomalies give more detail characters of the isostatic state and tectonic regime connected with one. Several isostatic anomalies: Airy, Glenni, Graaf-Hunter allow to determine geotectonic structures, which are conditioned by the masses on the several deep storeis. The isostatic reduced plumb line give some more characters about deep building and relation one with geotectonic structures. On the basis of this investigation the conclusion about geodynamic state of this region may be made.

THE DEVONIAN SUBSIDENCE OF BASINS OF THE EAST-EUROPEAN PLATFORM: JOINT INTERPRETATION OF OBSERVATIONS AND MODEL RESULTS

A. T. Ismail-Zadeh (Intl Inst Earthquake Prediction Theory & Math Geophysics. RAS, Warshavskoye sh. 79-2, Moscow 113556, Russia)

Tectonic subsidence analysis indicates that the East-European platform underwent two episodes of rapid downward motions since the Devonian time. Possible mechanisms of the rapid subsidences in the Timan-Pechora, Pre-Urals, Pre-Caspian, Dnieper-Donets, and Moscow basins of the platform are examined. Numerical models of these mechanisms are compared with seismic, gravity, heat flow, and Devonian magmatism observations from the basins. The models propose that the Devonian development of the basins is affected by one or more of the following processes: stretching of the lithosphere, thermal decay, mineralogical phase transition in the crust or uppermost mantle, subduction under the platform, continental collision. While some features of the basin evolution are in a good agreement with one of these models of mechanisms, no specific model can explain all features of the platform basins. The joint interpretation of geological and geophysical observations and results of numerical modelling supposes that eclogitization-induced mantle flow mechanism is likely to be responsible for the Devonian subsidence of the basins of the East-European platform.

GLOBAL ANOMALIES OF TIDAL GRAVITY FACTORS AND ITS POSSIBLE GEOPHYSICAL INTERPRETATION

A.Kopaev (Astronomical Institute of Moscow University, Universitetski prosp. 13, Moscow, 119899, Russia; fax: +7-095-9328841; e-mail: kopaev@sai.msu.su)

Simplified model estimations, based on extrapolation of mantle elastic parameters deduced from seismic data to tidal frequencies, suppose only modest anomalies (of about 0.2-0.5 %) of tidal δ-factors due to the mantle heterogeneities. However the simple statistical analysis of high quality tidal gravity data selected from ICET Data Bank demonstrates the existence of global anomalies in δ-factors with amplitudes up to 2 % correlated with CMB-topography and, possibly, with lower mantle viscousity. The correlation with heat flow seems much more complicated than previously supposed (prof. Melchior' hypothesys). Mean global values of δ-factors fit better to last versions of Wahr-Dehant models for frequency dependant Q with α=0.1 rather than for purely elastic models. All this means that tide gravity data may be essential in studying lateral anomalies of lower mantle viscousity that are hardly to detect by another methods. The lack of data in majority regions of the world excluding Europe represent however a serious problem.

EARLY TERTIARY "PALEO-GRAVITY" FIELDS OVER A NASCENT MACQUARIE TRIPLE JUNCTION

K. M. Marks (NOAA, Geosciences Lab., Silver Spring, Maryland, USA)
J. M. Stock (Caltech 252-21, Pasadena, California, USA)

We constructed "paleo-gravity" fields from satellite altimeter gravity by 1) removing gravity anomalies overlying seafloor younger than a selected age, and 2) rotating the remaining anomalies through appropriate finite rotations. We used Sutherland's (Tectonics, 1995) pole to close the Emerald Basin, and Cande et al. (Science, 1995) poles to roll- back spreading on the Pacific-Antarctic ridge. Chron 24 (53.35 Ma) gravity fields show Tasman seafloor juxtaposed against Pacific-Antarctic seafloor, and a continuous Tasman/Pacific-Antarctic ridge. Major N-S-trending fracture zones located on Pacific seafloor (east of the present-day Emerald Basin) line up with fracture zone traces on Antarctic seafloor. These fracture zones extend from the southwest margin of the Campbell Plateau to the Antarctic margin in the Ross Sea southeast of the Iselin Bank, and are embedded in seafloor generated by Tasman/Pacific-Antarctic spreading prior to C24. By C21 (47.91 Ma), these fracture zones have been sinistrally offset by a NW-SE-trending plate boundary transform that connects the Tasman ridge to the Pacific-Antarctic ridge. This offset requires seafloor spreading in the southwest, probably from the eastern tip of the Southeast Indian ridge (SEIR). This scenario suggests that eastward propagation of the SEIR to the Tasman/Pacific-Antarctic ridge (by C24 or older) led to the extinction of the Tasman ridge, at which time the Macquarie ridge formed (opening the Emerald Basin), and the nascent Macquarie triple junction was born.

GRAVITY AND SEISMOTECTONICS OF PAPUA NEW GUINEA: IMPLICATIONS FROM A GIS-APPROACH

P. Schmidt (Federal Institute for Geosciences and Natural Resources, Stilleweg 2, 30655 Hannover, Germany), Aruai, G., and Mosusu, N. (Department of Mining and Petroleum, Private Mail Bag, Port Moresby, Papua New Guinea)

Papua New Guinea's volcanoes belong to the most active ones in the world. During a three and a half months stay related to a technical cooperation project the principal author of this paper witnessed eruptions of Tavurvur (Rabaul), Mt. Ulawun (The Father) and Manam Island. These big threats to the local population mark the complex convergent plate boundary system between the Pacific and the Indo-Australian plates. The collision zone itself extends from South East Asia all the way to New Zealand. It is characterized by numerous smaller plates that are bordered by all kind of known types of plate boundaries.

Death of old and birth of new plate boundaries can be observed within PNG. This is indicated from geoscientific maps that have been analyzed together using a Geographical Information System. Gravity data, seismological and geological data have been considered. New spreading centers form within areas where subduction has recently ceased. Classic plate tectonical charts that cover the world do show plate boundaries that are much too simple to explain the processes that shaped and shape New Guinea and its surrounding islands.

POTENTIONAL FIELDS AS HISTORICAL CATEGORIES.

J.G.Koutinov, Z.B.Tchistova. Institut of Ecological Problems in the North, Urals Division of Russian Academy of Scs.Arkhangelsk, Russia

Potential fields are an important source of information for inderstanding geodynamics of continental riftogenesis. In the course of studies it was as certained that features of regional and local relations of gravity with magnetic, seismic and geological fields are one of the most important indicators, which enable to rather confidendly distinguish and typify paleorifts and kimberlite magmatism. In this case the potential field needs to be considered as historical categories.

GENERALIZED LEAST-SQUARES INVERSION APPLIED TO MODELIZE SEAFLOOR TOPOGRAPHY FROM ALTIMETRY AND IN-SITU DEPTH DATA

G. Ramillien, A. Cazenave , and P. Mazzega
(UMR 5566, CNES-CNRS, Toulouse, France)

Using altimetry data from the ERS-1 and Geosat Geodetic Missions, as well as in-situ depth measurements of the NGDC, a high-resolution (1/32° x 1/32°) global bathymetric grid has been computed using an iterative generalized least-squares inversion. The seafloor topography is computed in the waveband 15 - 500 km. At each iteration, the solution is constructed by a linear combination of the data (geoid or gravity anomalies, and in situ bathymetry) with adjusted coefficients. Isostatic compensation of the topography is taken into account through a lithospheric flexure model which depends upon crustal and elastic thicknesses, and density contrasts between water, crust and mantle. The elastic layer basement is assumed to follow an isotherm of the simple half-space cooling model. The considered a priori topography model is the ERS-1-derived bathymetry computed previously by Ramillien and Cazenave, using a 2-D spectral approach. A priori errors of data and model are taken into account via the covariance matrices. The inverted bathymetry is completed by wavelengths longer than 500 km using the long wavelength signal of ETOPO-5. Validation of the solution is performed through comparisons with long profiles of NGDC original soundings. Typical r.m.s. differences between computed and NGDC topography are found to be less than 100m.

THE METHOD OF JOINT INTERPRETATION OF DIFFERENT ELEMENTS OF GRAVITY AND MAGNETIC FIELDS

S.A. Serkerov (State Academy of Oil and Gas, Moscow, Leninskiy st., 65, 117917, Russia)
A.L. Kharitonov (Inst.of Terrestrial Magnetism, Tonosphere & Radiowave Propagat., Moscow reg., 142092, Troitsk, Russia)
V.A. Ponomarev (RAO "GasProm", Moscow, Russia)

The methods of joint interpretations of several of elements of one geopotential field were developed. For example, significances of initial measured field and its first vertical or horizontal derivative or different fields, that is of gravitational and magnetic fields. These methods have three considerable advantages: noise-stability, integrated approach of interpretation and relative sensitivity to form of sources of geopotential fields.The noise-stability is defined by theme, that interpretations of characteristic of elements of geopotential fields (power-energy spectra, crosscorrelation function) and statistical parameters of anomalies received with their use (correlation radius of crosscorrelation function, width of power-energy spectra of anomalies and other parameters). These parameters weak depends on the casual noises. The integrated approach of interpretation consists in joint use simultaneously of significances of different elements of geopotential fields.

THE DIGITAL GEOTRANSECT FROM THE EAST SIBERIAN CONTINENTAL SHELF TO THE DEEP ARCTIC OCEAN.

Sorokin M.(1), Maschenkov S.(2), Glebovsky V.,(2), Solodov V.(3) (1- Polar Expedition, 2-VNIIOkeangeologia, 3- Head Department of Navigation and Oceanography, St.Petersburg, Russia), Macnab R.(Geological Survey of Canada, Dartmouth NS), Kovacs L.C.(Naval Research Laboratory, Washington DC).

The poster presents a set of computer derived geophysical maps (bathymetry, magnetic anomalies, gravity), seismic cross-sections, and lithosphere model constructed on the basis of 2D-modeling along the Delong Islands - Makarov Basin Geotransect with the objective of achieving a better understanding of the deep crustal structure of the Arctic continental margin and poorly investigated Amerasia oceanic subbasin. The integrated interpretation of those data reveals several evidences of lateral crustal heterogeneity. The Makarov Basin is underlain by a fractured crust that is 10-15 km thick, which is intermediate between continental and oceanic crust.

GRAVITY ANOMALY AND COLLECTIVE PROPERTY OF ACTIVE FAULTS

K. Yamasaki and H. Nagahama (Institute of Geology and Paleontology, Tohoku University, 980, Sendai, Japan)

A differential geometrical equation of the gravity anomaly caused by the continuous distribution field of faults can be derived from Kondo's variational formalism which points out that the continuous defect field and gravity field have the similar geometrical structure. This geometrical equation can be applied to "plastic defects" expressed by the torsion and the curvature tensor of "crust-material space" for gravity changing. These geometrical objects are the equivalent to dislocation or disclination density tensors. Moreover, this geometrical equation can be also applied to the collective property of faults for gravity anomaly. When the rotational component on the fault displacement is spatially constant, the geometrical equation indicates that the negative gradient of the gravity anomaly increases with the increase of the fault density. On the other hand, the fault density increases with the decrease of the "mechanical thickness" of the lithosphere which posses the same strength for deformation. Therefore, the gradient of the gravity anomaly is expected to be negative in the region where the "mechanical thickness" is thin. Our geometrical equation can explain the reason why the negative gradient of the gravity anomaly surrounding the active fault or the minor earthquakes is higher in Northeast and Central Japan.

SE22 Elastic wave velocities in rocks: anisotropy, heterogeneity and frequency effects

Convener: Mainprice, D.
Co-Convener: Gueguen, Y.

EFFECTIVE ELASTIC CONSTANTS. COMPARISON OF DIFFERENT CALCULATION METHODS AND EXPERIMENTS

I.O.Bayuk and E.M.Chesnokov (Institute of Physics of the Earth, RAS, B. Gruzinskaya, 10, Moscow, Russia)

Using different approaches, the computer method for calculation of effective physical parameters (elastic, heat and electrical conductivity, and permeability) are developed. Numerical calculations indicate that all mathematical approaches give the similar results at low crack concentration. Effective properties found with the help of the most popular Eshelby's methods at constant applied strains in matrix are different from those obtained by the method at constant stress. The comparison of numerical results based on different mathematical approaches with experimental data (Fjaer et al.) demonstrates a good agreement with the results obtained with the help of the general singular approximation method only. The other methods bring to large deviation from the data considered.

EXPERIMENTAL STUDY OF THE SEISMIC PROPERTIES OF ISOLA D'ELBA METAMORPHIC BASEMENT (TUSCANY, ITALY)

L. Burlini (centro per lo Studio della Geodinamica Alpina e Quaternaria, CNR. Via Botticelli, 23, 20133 Milano, Italy)
S. Tancredi (Dept. of Scienze della Terra, Univ. Milano, Via Botticelli, 23 - 20133 Milano, Italy)
A. Zappone (Dept. of Scienze della Terra, Univ. Milano, Via. Botticelli, 23 - 20133 Milano, Italy)

In Tuscany (central Italy) a strong reflections at 5 to 10 km depth has been observed in the recent investigation by seismic reflection profiling (CROP-03). In order to better constrain the interpretation of the nature of this reflector, the seismic properties at pressure of up to 300 MPa confining pressure have been measured on several rock samples collected from the metamorphic basement of Tuscany exposed in the Isola d'Elba. The collected samples include metapelites, metavolcanics, granites and marbles from greenschist to upper amphibolite facies conditions. From each sample, the speed of ultrasonic waves has been measured on three mutually perpendicular directions, parallel to the rock reference frame (foliation and lineation). The maximum compressional wave velocity in most samples is parallel to the lineation whilst the minimum is normal to the foliation. Vp anisotropy is up to 15%
The seismic reflectivity of the anisotropic samples has been calculated for the rock sequence as exposed on the field. The reflectivity from the metapelite horizons is the strongest but its value cannot account for the strong reflection observed in the seismic profiles. Other causes, such as the high temperature and the presence of hot fluids together with the lithology must be considered for the origin of strong reflectors at depth.

GYROTROPIC PROPERTIES OF ROCKS DUE TO A DISSYMMETRY OF MICROSTRUCTURE

Chichinina T. I. (Institute of Geophysics of Russian Academy of Sciences (Siberian Branch), University pr., 3, Novosibirsk, 630090, Russia)

Anisotropy of rocks is a well known phenomenon. Recently, it was found (Obolentseva, 1992) that rocks can be not only anisotropic but gyrotropic as well. Anisotropy and gyrotropy are similar in the sense that they arise when the microobjects (with linear dimensions much less than the wave length) such as grains, thin layers, microcracks etc. are situated in a particular way in space. An anisotropy appears if the microobjects are parallel to certain planes or lines. For a gyrotropy to appear, the condition is rather simple: microobjects must be arranged so that the rock has no centre of symmetry. In this case the polarization of shear waves will be elliptical. If, moreover, the microobjects form a structure with prevailing right or left orientations, the effect of rotation of polarization plane will be observed. By now the phenomenological theory of elastic gyrotropy is developed. The problem is to present a microscopic theory or at least to construct specific micromodels of real rocks. We put forward one of such models — the model of a dissymmetric grainy medium which describes the gyrotropic properties of terrigeneous rocks consisting of isometric particles not less than 0.02 mm. In this model, the ability to rotate a polarization plane is due to a displacement of each lower contact point of a grain relatively the upper one in a particular way. The essence of the model is in this manner.Anisotropy and gyrotropy provide a possibility to recognize a microstructure of rocks through large scale observations of seismic waves.

THE ELASTIC AND VISCOUS PROPERTIES OF HIGHLY FRACTURED MEDIA

T. Dahm and Th. Becker (Institut für Meteorologie und Geophysik, Universität Frankfurt am Main, D-60323 Frankfurt am Main, Germany)

Highly fractured or foliated regions such as fault zones behave different compared to the homogeneous surrounding. In Seismology it is convenient to estimate effective elastic moduli from which the velocity of waves with wavelengths longer than the dimension of the cracks can be calculated. We simulated shear experiments using a boundary element method and a finite element method and calculated effective shear moduli of media containing strongly interacting in-plane cracks. Our numerical results are best approximated by the analytic formulas of a modified self-consistent theory which considers the crack-to-crack interaction in a simple manner. This seems to be in contradiction to numerical simulations of media containing anti-plane cracks performed by others, where a better approximation to a theory neglecting crack-to-crack interaction was found.
We additionally simulated numerical flow experiments in cracked media and found a behaviour of the effective viscosity similar to the one of the shear modulus in the elastic simulations, which indicates that the modified self-consistent theory can be used to estimate effective viscosities.

ATTENUATION OF ULTRASOUND IN ROCKS AT PRESSURE 1.5 GPA

G.A.Efimova (United Institute of Physics of the Earth, Russian Academy of Sciences, Bolshaya Gruzinskaya 10, Moscow, 123810, Russia)

A special technique developed for experimental determination of elastic wave attenuation coefficient in rocks at high pressures. It is the designed for high pressure cells of the "cylinder-piston" type with complex acoustical channel and based on the method of calibration and amplitude-frequency analysis. P-wave attenuation coefficients in granitoids depending on frequency and pressure has been measured by means of the technique offered. The results obtained show that attenuation, as against elastic velocities, is a more meaningful characteristic of microstructural alterations in samples.

THE INFLUENCE OF THE LOADING CONDITIONS ON THE PHYSICAL PARAMETERS VALUES OF ROCKS AT THE PHASE TRANSFORMATIONS UNDER HIGH PRESSURES.

G.A.Ephimova, S.M.Kireenkova
United Institute of Phyisics of the Earth, Russian Acad. of Sci.
B.Gruzinskaya 10, 123810, Moscow, Russia
A.N.Nikitin
Joined Institute of Nuclear Researches
Dubna, 141980, Moscow region.

The experimental investigations at high pressures of the elastic and deformational marble characteristics have been carried out in the piston-cylinder type at pressure up to 2.0 GPa and in the hadraulic pressure apparatus under constant pressure with additional axial compression at constant rate of $1.8 \cdot 10^{-6}$ mm/s. It is istablished, that the character of the elastic deformational parameters of marble changes and kinetic of the phase transformation is determined by the loading conditions and is attended with the textural changes. A change in the physical parameters of geomaterials, mainly deformational characteristics during phase transformation under high pressure is the criterion of the the amount appriation of conditions of the earthquakes preparation.

SEISMIC RESPONSE SIMULATION OF SEDIMENTARY LAYERS SEQUENCE BY MEANS OF ELECTRICAL TRANSMISSION LINES

F.Giordano* A. Rapolla** M. Ianniruberto*
*Istituto Universitario Navale -Napoli- Italy
**Dipartimento di Fisica e Vulcanologia Univ. Federico II Napoli

ABSTRACT
The response of a sequence of soil sedimentary layers to a seismic impulse by a sorgent located at deep can be described in time or in frequency domain. Obviously both descriptions are equivalent, but the second is the most often used. Several methodologies were used in the past to anticipate the seismic spectral character at the surface causing damage of buildings. We propose a simulation method for the behavior of a sequence of soil layers above a bedrock based on a set of electric transmission lines. We first examine a purely elastic model and afterword we introduce frictional loses. The results are compared with DAF tecnique. The results are equivalent while the proposed methodology results to be more compact. We finally made a synthetic test of a Phlegrean Field's site were a sequence of volcanic sands and pyroclastic layers above lithoid tuffs is present.

MANIFESTATION OF LINEAR ACOUSTIC ANISOTROPIC ABSORPTION IN ARCHEAN ROCKS OF KOLA SUPER-DEEP BOREHOLE

F.F. Gorbatsevich (Geological Institute KSC RAS, Apatity Russia)

Dichroism or phenomenon of linear anisotropic absorption is observed during the light propagation through optical media. A similar effect is displayed during elastic shear waves propagation in solids. By means of acoustopolariscopy method and acoustopolariscope we measure a display of linear anisotropic absorption effect (LAA) or acoustical dichroism in crystalline rocks. and others. This effect is also displayed in homogeneous but cracked media which the system of oriented cracks. As our experimental results showed, LAA effect may be displayed relatively independently of elastic anisotropy effect. It has been found out that this effect is displayed in rocks with oriented textures: linear, schistose and others (bearing amphibole, pyroxene, mica et al.). The two main types of LAA have been observed: plane and linear in the rocks of Kola super-deep borehole section. This effect, as well as strong elastic anisotropy, are displayed practically in all types of rocks (amphibolites, gneisses, migmatites, schists) at depths from 4.43 km to 12.26 km. It will influence the interpretation of seismic work results. For example, in the wave that has passed through the rock layers displaying this effect, a shear wave S_2 impulse will be weakened or fully suppressed. By shear wave characteristics such a geophysical section may be interpreted as isotropic by mistake.

P-WAVE VELOCITY ANISOTROPY (UP TO 400 MPa) OF ROCKS FROM THE NORTHERN VOSGES, FRANCE

G. Gong, R. Chessex, J.-J. Wagner (Department of Mineralogy, University of Geneva, 13 Rue des Maraîchers, CH-1211 Geneva 4, Switzerland)

P-wave velocity anisotropy, at confining pressures up to 400 MPa, has been measured in the laboratory on 41 dry rock samples (5 sedimentary, 29 igneous and 7 metamorphic) from the northern Vosges. All samples show a decreasing anisotropy and approach a constant value with increasing pressure; the mean high pressure anisotropy is of the order of 8% for the metamorphic-, 2% for the igneous- and 3% for the sedimentary rocks. There is no significant difference between igneous and sedimentary rocks. The velocity anisotropy is related to three basic factors. These are pore or fissure geometry, grain organisation and intrinsic mineral anisotropy. The latter two dominate at pressures higher than 200 MPa in the absence of fluids. The low pressure anisotropy of the sediments increases linearly with the porosity, which demonstrates an increasing role of the void geometry. Most of the igneous rocks (granites, diorites, diabases, andesites, rhyolites and dacites) have a very similar behaviour. Only the dacites exhibit an abnormally high anisotropy which could be related to a flow pattern. The metamorphics are represented by schists, gneisses, hornfels and greenschists. The schists have the largest high pressure anisotropy followed by the gneisses but both present a large spread in values and cannot necessarily be distinguished in terms of anisotropy. These results confirm that one should take into account the velocity anisotropy when modelling metamorphic basements.

ANISOTROPIC ELASTIC PROPERTIES AND THEIR RELATION TO ANISOTROPIC FLUID FLOW.

C. Jones & P.G. Meredith, Rock and Ice Physics Laboratory, Department of Geological Sciences, University College London, Gower Street, London, UK

Fluid flow in the Earth takes place in a network of cracks and pores which is potentially highly anisotropic. The anisotropic network can contribute to anisotropic elastic wave propagation phenomena such as shear wave splitting. In this study laboratory ultrasonic elastic wave propagation measurements are compared to the permeability as a function of direction. The rock used in this study is Tennessee sandstone, which is a fine grain sandstone with pronounced bedding. Samples were cored parallel and normal to the bedding. Compressional wave velocity was measured diametrically as a function of angle relative to the bedding. The velocity varied from 4.2 kms-1 for propagation normal to the bedding to 3.2kms-1 parallel to the bedding. Shear wave anisotropy was determined by making measurements of transmitted amplitude with cross polarised source and receiver transducers. The results showed minima with the source polarised at 450 relative to the bedding plane. The most likely explanation for these measurements of elastic anisotropy in this rock is that there is a preferential alignment of cracks and pores in the plane of the bedding. Permeability measurements were made to determine the effect on the transport properties of this preferential alignment of cracks and pores. The samples were found to have a strong permeability anisotropy with the permeability parallel to the bedding 2-3 times greater than that normal to the bedding.

ANISOTROPY OF LONGWAVES IN ROCKS WITH CRACKS AND PORES OF VARIOUS SHAPES (DRY AND FLUID-FILLED)

MARK KACHANOV Dept. of Mechanical Engineering, Tufts University Medford MA 02155 USA
Boris Shafiro Dept. of Mechanical Engineering, Tufts University Medford MA 02155 USA

Effective elastic properties of solids with pores of various shapes and arbitrary orientational distributions are derived. In particular, mixtures of defects of diverse shapes are considered. These results are applied to longwave speeds. A particular attention is paid to anisotropies due to preferential orientations of cavities of various shapes and to the number of independent constants and wavespeeds. We also analyzed pores filled with compressible fluid and the impact of the fluid on the anisotropic wavespeed patterns. "Fluid signatures" in these patterns are identified in the case of narrow, crack-like pores.

Anisotropy of wave velocity and attenuation in low-porosity, crystalline rocks

H. Kern and T. Popp (Mineralogisch-Petrographisches Institut, Olshausenstr.40, 24098 Kiel, Germany)

The directional dependance of ultrasonic P- and S-wave velocities (Vp and Vs) and their respective Q-values (Qp and Qs) were measured in foliated serpentinite and amphibolite as a function of pressure and temperature (at 100 and 600 MPa confining pressure). Both rocks exhibit a pronounced lattice preferred orientation (LPO) of the main mineral phases antigorite and hornblende, respectively. The experimental data document substantial anisotropies of velocity and of Q in P- and S-waves, but with different origin. Maximum anisotropies of Vp and Vs are observed at low confining pressures due to the constructive interference of effects related to oriented microcracks and to the LPO of major minerals. Increase in pressure decreases velocity anisotropy at an increasingly smaller rate. The residual velocity anisotropy (and shear wave splitting) observed at high confining pressure is mainly due to preferred mineral orientation. The reverse is true for the anisotropy of Q, at least for Qp: anisotropy is low at low confining pressure and markedly enhanced as pressure is increased. Qp is found to be highest in the direction normal to the foliation plane, whereas Vp (and Vs) is lowest in this direction, and thus reversed from that of P-wave velocities. The pressure-induced anisotropy of Qp is attributed to a directionally dependent increase of contact areas on the oriented grain boundaries of the platy minerals defining the foliation.

INVESTIGATION OF TEXTURIZED SOLID BODIES BY ULTRASONIC WAVES AND NEUTRON DIFFRACTION

Z. Pros, K. Klima, T. Locajicek (Geophysical Institute, Czech Academy of Sciences, Bocni II , 141 31 Prague 4 , Czech Republic)
A.N.Nikitin (Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia)
T.I.Ivankina (Teacher's Training University, 300026 Tula, Russia)

The results of the investigation of the relationship among texture of solid bodies (for examples, rocks) and their physical properties, especially kinematic and dynamic parameters of acoustic waves are presented. The study of the anisotropy of P-wave velocities has been made on spherical samples in a range of confining pressure from 0 to 400 MPa. The spherical shape of the sample enable to investigate the spartial distribution of P-wave velocities for any pressure value, and this can then be used to derive the changes of velosity with pressure for any direction in space. For determination of the sample texture the standart procedure for pole figure measurements by the time-of-flight method was used. Texture research was carried out on the rock samples (marble and olivine) at the JINR, Dubna, Russia. The results of neutron texture analysis allows to interpret the elastic anisotropy of rock samples.

THE INFLUENCE OF THE MINERAL COMPOSITION ON THE ELASTIC CHARACTERISTICS OF ABYSSAL ROCKS UNDER HIGH PRESSURE.

S.M.Kireenkova
United Institute of Phyisics of the Earth, Russian Acad. of Sci.
B.Gruzinskaya 10, 123810, Moscow, Russia

The influence of the mineral composition on the elastic characteristics magnitudes of rocks is considered on the basis experimental study under pressures up to 2.5 GPa of the velocities of longitudinal and shear waves propagation, the density and the compressibility of the rocks in the crust abyssal zones and xenoliths from explosion tubes of different regions. It is shown, that the value of the elastic characteristics of abyssal rocks and their behavior under pressure are greatly affected by the compositions of basic rock-forming minerals (garnet, pyroxene, olivin), mineral percentage in rocks, proper anisotropic properties of minerals and the number of oriented grains of the minerals in rocks. It is established that the elastic waves velocities, especially the shear waves velocities, in the greater degree depend on changes in the mineral composition and structural characteristics of rocks. The density and especially the compressibility does not depend on structural hetorogeneity and are determined by the rock-forming minerals compressibility under pressures more 1-1.5 GPa.

FREQUENCY EFFECTS IN POLARIZATION ANOMALIES OF SEISMIC WAVES. A THEORETICAL BACKGROUND

A.P. Kiselev and V.O. Yarovoy (Institute of Mechanical Engineering, V.O.Bolshoy 61, StPetersburg, 199178, Russia)
Yu.V. Roslov(NIIF, St.Petersburg University, St.Petersburg, 198904, Russia)

We describe recent theoretical results concerning the effects of inhomogeneity, anisotropy and anelasticity of the medium on polarization anomalies of body waves. Our aim is distinguishing these effects by processing of polarization data. First, we find that for a smooth inhomogeneity when the ray theory based on curved rays is applicable, the waveform in anomalous (or additional) components is stable. Its dominant frequency is lower than that in the 'normal' component. Next we consider a low-contrast interface, near which an interference of the incident\transmitted wave with the reflected and converted waves produces an effect of polarization anomalies. The waveforms in the anomalous components are now chaotic. Anisotropy (at least not a too strong one) effects in relation between the direction of propagation and the normal to a wavefront, other than that for an isotropic media but no new frequency-dependent phenomena arise. The effect of Maxwell-Boltzmann-Volterra anelasticity on the polarization is similar to that of the smooth inhomogeneity. More detailes can be found in: [1] A.P. Kiselev and Yu.V. Roslov, The use of additional components in numerical modelling of polarization anomalies, Sov. Geol. Geophys. 32, n.4, 1991; [2] A.P. Kiselev and V.O. Yarovoy, Diffraction, interference and depolarization of elastic waves. I. Phys. Earth. n.10, 1994; [3] A.P. Kiselev, Ray theory of body waves in inhomogeneous viscoelastic media. PAGEOPH 140, n.4, 1993; [4] A.P. Kiselev, Body waves in weakly anisotropic medium. - I. Geoph. J. Int. 118, n.2, 1994.

ELASTIC WAVE PROPAGATION IN ROCK WITH THIN INCLUSIONS.

N.A.Lavrov, E.E.Pavlovskaya
Institute for Problems of Mechanical Engineering of Russian Academy of Sciences

Harmonic wave propagation in rock with rod-like and thin-walled elastic inclusions is under consideration. Incident wave length is assumed to be comparable with the large linear size of inclusion. Direct numerical solution (FEM, BEM, FDM) of this 3D problem of elastodynamics is connected with the principal difficulty caused by the degeneration of the region (presence of a small geometrical parameter). To overcome this obstacle the proper asymptotic approach is proposed. Asymptotic integral equations of motion are derived on the basis of the approach above and are suitable for numerical solution (their kernels do not contain improper integrals of oscillating functions). Wave propagation in rock containing a system of inclusions is analyzed numerically and the displacements and the stresses are calculated.

RECONSTRUCTION OF THE COMPLEX STRESSED STATE OF GEOBLOCKS USING RESULTS OF STUDIES OF ELASTIC ANISOTROPY OF ROCKS

T.S.Lebedev, V.A.Korchin, P.A.Burtny (Institute of Geophysics, Nat Ac Sci Ukr, Kiev-142, Ukraine 252142)

Detailed studies of the interaction of an ultrasonic longitudinal and transverse linearly polarized wave with elements of elastic symmetry of rocks at differently oriented high preassures and temperature distribution discover features of physical nature of elastic anisotropy of mineral media. The latter is due to crystal-structure and texture characteristics of rocks, oriented localization of their macro and microdefects as well as paleo- and technogenetic stress in specific geologic bodies. Such studies combined with geophysical field observations enable us to characterize the complex stressed state of some geoblocks of the upper crustal horizons. As an example a respective analysis of the areas of Krivoy Rog and Kola ultradeep boreholes and the South-Ukrainian NPP construction has been made.

DENSITY MODEL OF THE LITHOSPHERE IN THE ZONE OF SUUSAMYR EARTHQUAKE (BY SEISMOTOMOGRAPHY DATA)

Oksana M.Lesik, Experiment-methodical expedition IVT RAS, 720049 Bishkek-49, Kyrgyzstan.

This study is a part of the investigations geophysical criterions for the distinguishment focus zone of the major earthquakes. The detection of the rock complexes which are differed by physical properties is significant seismotectonic problem. Structural layers which have different physical properties are characterized by diverse degree of the dislocation. The hardest solidest layers form the general framework, but less solid plastic layers are displaced about first ones and crumpled in the folds. A interrelation between the hard and plastic layers, their ability for an accumulation and a realization of the tectonic strains define seismotectonic conditions. In this paper are described the results of the study of the distribution of the densities and other elastic parameters which were calculated by using seismotomography data in the zone Suusamyr earthquake (M=7.3) which occured on 19 August 1992 in North Tien-Shan. Its aftershock process continuies to develop to present time. The focus zone which is countoured by aftershocks was consistenly developed on latitude direction (from east to west) and then changed its strike to NE.The sizes of the zone are roughly 80 km along and 10-15 km across. Using P- and S-wave velocity were calculated density by empiric formulas. Then calculating densities were used for determination other elastic parameters: Young's modulus, shear modulus, coefficient of general compression and Poisson ratio. The sections with these parameters were constructed along and across of the focus zone Suusamyr earthquake. Analysis of the data obtained allowed to reveal low density layers which provide the possibility of the strike-slip between layers and also high density competent layers which wrap the aftershock area. These results were compared with the geology structure and geodinamics of this region that allowed to deduce about the dinamic processes in the focus zone of the Suusamyr earthquake.

ANALYSIS OF SCATTERED WAVES USING COHERENCY FUNCTION.

A. Leśniak (Department of Geophysics. University of Mining and Metallurgy, al. Mickiewicza 30, 30-059 Kraków, Poland)
H. Niitsuma (Department of Geoscience and Technology. Tohoku University, Sendai 980-77, Japan)

The objective of the crosswell experiment carried out in Hachimantai field, Japan, was to determine the spatial scale of heterogeneities by studying the scattered modes of the wavefield (coda). To determine the scale of heterogeneities, we used the corelation coefficient of the coda on adjacent traces. The coda modes may have a different frequency so it is convinient to study the correlation in frequency domain using the time-frequency coherency function. The boreholes were drilled into the welded tuff, which is almost homogeneous above the depth of 335m in this area. Below this depth different scale heterogeneities were found. We made the measurements using a three component wide-band seismic detector. Because of a short propagation distance, the detected frequency range of the signals was from 100 Hz to 5 kHz. During the experiment we kept the detector at the same depth in one borehole and moved the source with the 20cm step in the other. Then, we evaluated the coherency between the different recorded traces in a short moving window to examine the similarity of the traces in time. The average coherency between two traces depends on spatial separation of the traces. The coherency is greater for small separation while for greater separation coherency decreases. We have evaluated the size of heterogeneities for two layers, one homogeneous and the second heterogeneous.

MODELING THE ANISOTROPIC SEISMIC PROPERTIES OF PARTIALLY MOLTEN ROCKS FOUND AT MID-OCEAN RIDGES

David Mainprice (Laboratoire de Tectonophysique, CNRS UM5568, Université Montpellier II, 34095 Montpellier Cedex 05,France)

The problem of modeling the seismic properties of mid ocean ridge rocks of the axial magma chamber and the low velocity triangle immediately below it has been addressed using two samples from Oman opholite as examples from a fast spreading ridge. A layered gabbro from the lower oceanic crustal sequence and a harzburgite from the upper most mantle section at the palaeo ridge axis. These rocks have a strong back ground elastic anisotropy due to crystal preferred orientation (CPO) and an additional anisotropy due to oriented melt filled inclusions. The seismic properties have been simulated at a temperature of 1200°C and pressure of 200 MPa so that the basalt melt is above its solidus. A tensorial model was developed using a poro-elastic method of Gassmann at low seismic frequency and a standard DEM with isolated basalt inclusions at high frequency. Calculations with spherical basalt inclusions show that the seismic velocities decrease and attenuation increase with increasing melt fraction. The symmetry of the back ground anisotropy due to CPO is preserved, but the anisotropy is gradually reduced with increasing melt fraction. With ellipsoidal basalt "pancake" shaped inclusions with their circular sections in the (XY) foliation plane, only a 2-3% of ellipsoidal basalt inclusions are required to over print the anisotropy of the background medium. There is a rapid decrease in Vp and increase of Q^{-1} for propagation normal to the foliation (Z) with increasing axial ratio of the inclusions. With increasing axial ratio the model predicts decreasing amounts of melt for given velocity Vp in the Z direction.

DAMAGE EVOLUTION AND WAVE PROPAGATION IN HETEROGENEOUS ROCKS: MODEL BASED ON STOCHASTIC DIFFERENTIAL EQUATIONS

L. L. Mishnaevsky Jr (IAMT, Kiev, Ukraine. Currently: MPA, University of Stuttgart, Germany)

A mathematical model of damage evolution and localization in heterogeneous rocks under dynamical loading is developed with the use of stochastic differential equations. The effect of random variations of local rock properties on the damage evolution and wave propagation in rock is taken into account by including fluctuating terms in the damage evolution law and wave propagation equations. The wave propagation equations are modified also in order to take into account the influence of local damage on wave velocity; in so doing, the Lemaitre's strain equivalence principle is used. Solving the stochastic differential equations numerically, one demonstrates that the damage localization takes place under such conditions. In the loaded volume regions with high and low density of microcracks are formed. The dependence of averaged correlation coefficient of damage parameters in neighbouring points (which is used here as a characteristic of the degree of damage localization) on the conditions of loading is studied numerically as well. The influence of the damage evolution on the propagation of elastic waves, wave velocities, energy dissipation is considered. An analogy between the damage localization caused by both stochastic effects and non-linearity of equations, and the formation of dissipative structures in self-organization processes is discussed. The results of simulation are compared with the experimental data on impact loading of rocks.

ANALYSIS OF CODA WAVES PRODUCT BY SHOTS RECORDED BY A DENSE ARRAY AT MT. VESUVIUS VOLCANO, ITALY.

Del Pezzo E.1, De Luca G.2, La Rocca M.1, Scarpa R.2, Simini M.1.
1 Physics department. University of Salerno, Via S. Allende - 84081 Baronissi (Salerno) - Italy. fax(39)89953804.
2 Physics department. University of L'Aquila, via Vetoio - 67010 Coppito (L'AQuila) - Italy fax (39)862433033

Shot data from a portable dense array deployed on Mt. Vesuvius in June 1996, durind a 3D seismic tomography experiment, are analyzed in the present paper. The array consisted of two groups of short period geophones, 4.5 Hz natural frequency, formed by 36 vertical components and 42 horizontal components. A study of the seismic coda of three shots was carried out using both vertical and horizontal components. The purpose was to measure azimuth, apparent velocity and composition of the waves that compose the coda in the frequency range of 2-8 Hz. We used the Zero Lag Crosscorrelation method to obtain the components of the apparent wave vector, and three component analysis tecniques based on the covariance matrix of the signal in time domain to investigate on the polarization properties of the signals. We compared coda waves of shots with coda waves of small eartquakes recorded on Teide Volcano - Canary Islands (Spain) in 1994 analysed in the same way.

SEISMIC PROPERTIES OF THE METAMORPHIC BASEMENT OF TUSCANY: AN EXPERIMENTAL APPROACH

G.Pinna (Dept. of Scienze della Terra, Univ. Pisa Via S.Maria,53 - 56126 Pisa, Italy)
L.Burlini (Centro per lo Studio della Geodinamica Alpina e Quarternarina, CNR, Via Botticelli,23 20133 Milano, Italy)
D.Mainprice (Laboratoire de Tectonophysique, CNRS UM5568, Université Montpellier II, 34095 Montpellier Cedex 05,France)
E.Pinna (Dept. of Scienze della Terra, Univ. Pisa Via S.Maria,53 - 56126 Pisa, Italy)

In Tuscany (central Italy) there is a geothermal region characterised by a very high heat flow (up to 200 mW/m2) and temperatures of up to 400°C at 3 km depth. The geothermal energy is exploited by a series of deep (up to 4km) boreholes. Recovered samples include metapelites, granites, gniesses and amphibolites from greenschist to upper amphibolite facies conditions. Samples have been characterised by modal analysis and crystal preferred orientation with view to calculating physical properties. Several samples have been cored (1.5cm diameter) for laboratory measuement of seismic velocity at pressures up to 300 MPa. Calculated and laboratory measurements have been compared.
The seismic refelectivity of the anisotropic samples has been calculated for the rock sequence found in the boreholes. The reflectivity from the metapelite horizons is very strong and certain combinations of lithology may correspond to the stong seismic reflector in the Larderello area (K-horizon) observed in the seismic profiles performed by CROP-30 and ENEL.The high temperatures and presence of hot fluids present several possibilities for the origin of strong reflectors at depth.

VELOCITY DISPERSION AND SCALES

M. Le Ravalec
Geophysics Dept, Stanford University, Stanford, Ca 94305-2215, US.
Y. Guéguen
Laboratoire de Geologie, Ecole Normale Superieure, 24, rue Lhomond, 75230 Paris Cedex 05, France.
T. Chelidze
Insitute of Geophysics, 1, Rukhadze str., 380093, Tbilisi, Georgia.

The heterogeneous geological nature of rocks often results in the heterogeneity of the fluid distribution in the pore space. A two-phase saturation can be heterogeneous at variable scales ranging from the laboratory scale to much greater scales. This heterogeneity has a significant effect on velocities. The sizes of the heterogeneities are associated to characteristic frequencies. At lower frequencies, the fluid is relaxed, whereas at higher frequencies, the fluid is unrelaxed. Our purpose is to model velocities in porous/cracked rocks with a two-phase saturation. Two scales of heterogeneity are distinguished. The first one corresponds to the pore size. It is the scale of the local flow dispersion and depends on local variations in pore/crack compressibility. The second scale is much greater and is defined by patches that are surrounded by regions with a distinct saturation level. These patches are the scale of the global flow dispersion that depends on fluid pressure equilibration among regions with different saturations. Our model is based upon the Effective Medium Theory (differential self-consistent approach). We propose to examine two applications: (1) the modeling of velocities measured on a sample submitted to an imbibition/drainage process at the laboratory scale and (2) the modeling of the velocity anomaly observed prior to some earthquakes at the in-situ scale.

TOMOGRAPHIC IMAGING IN ANISOTROPIC MEDIA: RESULTS FROM STUDIES OF MID-OCEAN RIDGES

D.R. Toomey, A.H. Barclay, R.A. Dunn, W.C. Hammond (Dept. of Geological Sciences, University of Oregon, Eugene, OR, U.S.A.)

Tomographic imaging of upper mantle or crustal structure from the delay times of P and S body waves often assumes that the structure is isotropic, an assumption that may be invalid in at least two important settings: In regions where upper mantle deformation gives rise to a preferred orientation of olivine crystals and in areas where the trend of crustal faults and cracks are aligned in response to tectonic stresses. We review our efforts to constrain the nature of seismic anisotropy and heterogeneity within the crust and mantle beneath fast- and slow-spreading mid-ocean ridges. Data analyzed include delay times of P and S body waves from both active and natural sources, and the splitting of S waves from earthquakes recorded by three-component ocean-bottom seismometers. To analyze these data we have developed tomographic methods that allow simultaneous inversion of P and S wave delay times for both heterogeneity and anisotropy. Results will be presented for crustal anisotropy beneath the Mid-Atlantic Ridge and upper mantle anisotropy beneath the East Pacific Rise. The constraints on crustal anisotropy yield insights to crack density and hence permeability, whereas results from the EPR constrain the geometry of mantle flow beneath the rise axis.

PARAMETERS OF SEISMIC WAVES IN EARTH'S CRUST

T.Verbitsky, Yu.Verbitsky (Carpathian Branch of Institute of Geophisics NASU, 3 "b" Naukova str., 290601, Lviv, UKRAINE)

Mathematical models of porous rocks [T.Z.Verbitsky. Phisical nature of the non-linear elasticity of geological media with phase nonhomogeneities. Geofiz. Sb. Ukr. Acad. Nauk. Kiev: Naukova Dumka, 1977, N75, p.p 16-23 (in Russian)] and focal mechanism [I.Kawasaki, Y.Suzuki, R.Sato. Seismic waves due to shear fault in a semiinfinite medium. Part II. J.Phys. Earth. V.23, N1, 1975, p.p. 43- 61] is used for research of influence stress, woter saturated and microcracks medium on parameters of various types seismic waves. Numerical experiments has shown, that the increase of a pressure on the rock causes decrease of arrival times P-,S- and R-waves at some increase of amplitude P-wave. The decrease of rocks saturated by water at initial stage is accompanied increase of arrival time P- and R- waves at constant parameters S- wave. Further decrease saturated does not practically influence parameters seismic waves. Growth of microcracks in rock causes increase of arrival time P-wave, and especially large - for S- and R- of waves, at small decrease of amplitude P-wave and strong growth of amplitude of a S-wave. A principle possibility of determination of a nature abnormal changes of parameters seismic waves and use discoverable peculiarity for creation of a technique monitoring seismotectonics processes in earth's crust is shown.

THE EFFECT OF OVERBURDEN VELOCITY HETEROGENEITIES ON SALT DOME SHAPE INTERPRETATION BY TRANSMISSION METHOD

KASINA ZBIGNIEW
KALUZA MARCIN
SLYSZ JOANNA

UNIVERSITY OF MINING & METALLURGY
Faculty of Geology, Geophysics & Environmental Protection
Cracow, Poland

Knowledge of the shape of a dome plays the main role in projecting localization of gas reservoir in salt domes. One of the cheapest seismic methods used to define dome shape is the method of transmission between surface and salt well. In the suggested interpretation's variant we assume often appearing in practice measurement case, where receivers are located in the well within salt dome and the source is located on the surface (Vibroseis) or in a shallow shot hole.
The presented algorithm and computer program make it possible to interpret the results of seismic transmission method taking into account refraction of seismic ray on the intermediate boundaries in the dome overburden as well as the velocity gradient in dome's surroundings.
Program has been tested on the model and field data

SE23 Relationship between various properties in sedimentary and crystalline rocks

Convener: Huenges, E.
Co-Conveners: Kukkonen, I.T.; Urai, J.L.

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND SEDIMENT PROPERTIES OF NEAR SURFACE MARINE SEDIMENTS

A. Ayres, F. Theilen
Institut für Geophysik der Christian-Albrechts-Universität zu Kiel
Leibnizstr. 15, 24118, Kiel, Germany

Seismic velocities of compressional (P-) and shear (S-) waves are important parameters in characterizing marine sediments with respect to sedimentological and geotechnical properties.Even though clay sediments constitute 75% of the clastic fill of sedimentary basins, very little is known about the behavior of seismic waves in fine grained material. Three large Box-Cores were recovered at the continental slope of the Barents Sea for petrophysical, geological and geotechnical investigation on board ship. The P-wave velocities are within the expected range close to water velocity, while S-wave were much lower than expected. The wider range of velocities exhibited by the S-waves (from 9 to 47 m/s in the upper 9m below sea bottom) suggests that V_s is much more sensible to changes in sediment properties than Vp. S-wave velocity also shows good correlations with sediment properties such as clay and silt content, wet bulk density, porosity, water content and shear strength. The reflection coefficients of S-waves are also characterized by a good correlation with P-wave seismic reflectors.

CORRELATION BETWEEN ELASTIC AND TRANSPORT PROPERTIES OF POROUS CRACKED ANISOTROPIC MEDIA

I.O. Bayuk and E.M. Chesnokov (Institute of Physics of the Earth, RAS, B. Gruzinskaya, 10, Moscow, Russia)

Numerical schemes based on different mathematical approaches for calculation of effective elastic and transport properties (heat and electrical conductivity, and permeability) are developed. For different types of porous cracked anisotropic media with various distribution functions (over aspect ratio and angular orientation), elastic and transport properties are calculated simultaneously. As shown, elastic properties allow one to distinguish media with liquid and empty inclusions. Sort of the liquid is possible to recognize using the results of electrical conductivity calculations. Simultaneous calculations of elastic velocities and permeability give the chance to estimate permeability using seismic velocities.

A model for the inversion of horizontal stresses in sedimentary basins from surface area measurments on drill cuttings

Wolfgang. K. Heidug, Shell International Exploration and Production, NL-2280 AB Rijswijk;
Janos L. Urai, Endogene Dynamik, RWTH , D-52056 Aachen;
Melvyn R. Giles, Shell International Exploration and Production, NL-2280 AB Rijswijk.

We present a modified version of the Cam-clay model that involves a reformulation of the hardening rule to incorporate the geophysical observation on porosity loss that is expressed by Athy's law. Using it, we quantify the effect of horizontal stress on porosity reduction. Moreover, we obtain an equation for the horizontal stresses in a basin during inelastic, uniaxial compaction. To validate our compaction calculations we apply them to the northern part of the North Sea basin. The strength parameter M in the Cam-clay model is estimated by exploiting its correlation to the specific surface area of the minerals in the basin fill. The variation of this quantity with depth is known from measurement on drill cuttings. On comparing theoretical predictions with measured leak-off pressure data, which we take as proxies for the horizontal stress, we find reasonable agreement. The agreement improves further when the functional dependence between horizontal stress and M is modified according to a proposition by Jaky.

3-D -Petrophysics in a Selected Area of the Northeast-German Basin

A. Gardei, E.Huenges, P. Hoth and E. Spangenberg
(GeoForschungsZentrum Potsdam, Telegrafenberg, D14473 Potsdam)

A 3-D-petrophysics study was started for the north-east-end of an actual seismic profile running from the island of Rügen to the Harz mountain (Northeast Germany). 15 boreholes with depths up to 7,5 km within a radius of 20 km was the case of our interpretation. Existing borehole measurements are combined with new petrophysical measurements on core samples. Elastic and electric properties as well as radiogen heat production are compiled and collected in a data bank. The data represent selective properties in different depths related to geological layers. First results show, that petrophysical properties of the layers vary regional. The goal of this work is a geostatistic base, to link with seismic and gravimetric data and a continuous 3-D-classification of petrophysical properties.

Relationship between geothermal and hydrogeological parameters in sedimentary rocks

Khodyreva Ella Jakovlevna

On the basis of statistical analysis of the results of the geothermal investigations carried out in the long-standing deep borcholes it have been established quantitative connections between geothermal and hydrogeological parameters in sedimentary rocks. The method of non-linear geothermograms interpretation is developed and the quantitative estimation of non-linear coefficient is given according to the theoretic solution of the problem of temperature distribution due to depth in a medium with heat conductivity of rocks changing by the law $L=Lo(1+az)$. Relationship between the heat conductivity of rocks and thermic capacity, density and velocity of fluid motion has been established.

HIGH GRADE ROCKS OF FINLAND AND ESTONIA: HEAT PRODUCTION AND THERMAL CONDUCTIVITY

A. Jõeleht (University of Tartu, Vanemuise 46, EE2400 Tartu, Estonia)
I.T. Kukkonen (GSF, P.O. Box 96, FIN-02151 Espoo, Finland)

We measured heat production, thermal conductivity and P-wave velocity from saturated samples at room pressure from five granulite facies rock areas of Finland and Estonia (Varpaisjärvi, Pielavesi-Kiuruvesi, Lapland, Turku and southern Estonia). The rocks are Archean and Early Proterozoic in age and are mainly intermediate in composition. The heat production values averaged by areas vary from 0.57 to 2.24 $\mu W\ m^{-3}$. The lowest values are in the Varpaisjärvi area that is the oldest, most mafic and where the highest metamorphic pressure occurred (9 kbar), whereas the highest heat production exists in the Turku granulite belt where the metamorphic pressure was about 5 kbar. In general, the heat production decreases with increasing metamorphic pressure. Our data suggests no relationship between heat production and P-wave velocity. The mean thermal conductivity of granulites by areas vary form 3.0 to 3.5 $Wm^{-1}K^{-1}$. Slightly elevated thermal conductivity values in the Varpaisjärvi and Lapland granulite areas can be attributed to higher sillimanite and quartz contents, respectively.

RELATIONSHIPS BETWEEN THERMAL AND OTHER PETROPHYSICAL PROPERTIES OF ROCKS IN FINLAND

I.T. Kukkonen (Geological Survey of Finland, P.O. Box 96, FIN-02151 Espoo, Finland, e-mail ilmo.kukkonen@gsf.fi

S. Peltoniemi (Helsinki University of Technology, Laboratory of Engineering Geology and Geophysics, Vuorimiehent. 2, FIN-02150 Espoo, Finland)

We report results of a petrophysical study based on 2700 rock samples used originally for thermal conductivity measurements in heat flow studies in Finland. In addition to thermal conductivity, also density, P-wave velocity, magnetic susceptibility, intensity of natural remanent magnetization and radiogenic heat production were measured from all suitable samples. The samples were geologically classified into lithological types, and they represent all major crystalline rock types. Weak correlations were found to exist between the following pairs of properties: thermal conductivity vs. density, thermal conductivity vs. P-wave velocity, and thermal conductivity vs. susceptibility in paramagnetic rocks. The results are too noisy for estimating the thermal conductivity or the other properties with the aid of the relationships. Further, no distinct relationship was observed between thermal conductivity vs. heat production, or thermal conductivity vs. remanent magnetization. Heat production does not show any distinct relationship with P-wave velocity or density in our data set, and the heat production data are scattered over three orders of magnitude. Implications on estimating crustal thermal parameters with the aid of petrophysical relationships are discussed in the paper.

THERMAL CONDUCTIVITY OF SEDIMENTS, DERIVED FROM GEOPHYSICAL LOGS - NEW CALIBRATION BY CORES AND CUTTINGS

W. Leu and E. Greber (GEOFORM AG, CH-8401 Winterthur, Switzerland)
L. Rybach (Institute of Geophysics ETHZ, CH-8093 Zurich, Switzerland)

Three different empirical relationships to determine thermal conductivity λ from logging profiles of neutron porosity Φ_N, sonic velocity v_p, and bulk density RHOB in boreholes traversing Tertiary Molasse sediments have been calibrated with laboratory measurements on cores and cuttings from the same boreholes. The borehole profile lithologies consist of marls and sandstones from the Upper Marine Molasse, Lower Sweetwater Molasse, and Lower Marine Molasse formations. The calibration results, considered to be valid for the Swiss Molasse basin, are:

$\lambda 1 = -1.71 + 0.97 v_p - 0.022 \Phi_N$
$\lambda 2 = 0.54 v_p$
$\lambda 3 = -8.64 + 4.27 RHOB$

λ is in W/m,K, Φ_N in %, v_p in km/s, and RHOB in g/cm^3. The $\lambda 2$ values fit the core/cuttings data best, within $\pm$ 5-10 %.

HYDROGEOLOGY OF THE UPPER CRUSR IN THE AREA OF KOLA HOLE - GEOTHERMAL ASPECTS

Leonid V.Borevsky (HYDEC Research Company, 15 Parkovaya, 10a, 105203, Moscow, Russia). Svet.Yu.Milanovsky (UIPE RAS, B. Gruzinskaya 10, 123810, Moscow, Russia) Vladimir I. Morgachev and Vladimir N.Orlov (Pechenganickel, Russia)

On the Baltic Shild we have low average heat flow values. Very often these values have a big scatter. The dominant factor causing this phenomena is fluid flow in the cristalline rocks. The observed complicate picture of the heat flow distribution can be explained by very irregular permeability (cracked-tipe) of metamorfic rocks on the Shield. The permeability depends also from tectonic and lithological factors. The zone of exogenous fissuring about 800 m depth was established by hydrogeological study on Kola Peninsula. In the area of Kola hole we have the unique opportunity to investigate in details relationship between space pecularities of thermal field and hydrogeology. We present a new data about thermal and hydrogeological fields around Kola hole. This information is used for the interpretation of deep heat flow in Kola hole and heat-mass transfer in the upper crust.

SURFACE AND BOREHOLE ROCK SAMPLES PHYSICAL PROPERTIES AT SIMULATED NATURAL CONDITIONS.

G. Losito (Appl.Geoph. Lab., Deep. Civil Engineering, Univ. of Florence, via di S.Marta 3, I-50139 Firenze)
M. Muschietti and A. Trova

Electrical, elastic, hydraulic, and density parameters of rock samples have been studied at in situ simulated physical conditions in laboratory. The rock samples, that come both from surface and boreholes (up to 6500 m depth) in selected Italian areas, are triassic sedimentary rocks, carboniferous black shales and volcanic rocks. The operating physical conditions are : electrical frequency (0.001-200 Hz), temperature (up to 1000 C), confining pressure (up to 40 Mpa), internal pore fluid pressure (up to 20 MPa). The rock physical behaviour has been interpreted on the basis of mineralogical analysis.

EXPERIMENTAL SIMULATION OF IN SITU CONDITIONS - CHALLENGES; TASKS AND LIMITATIONS

H.J. Mueller (GeoForschungsZentrumPotsdam, Telegraphenberg A6, D-14473 Potsdam, Germany)

In general the history of science reflects - new data destroy old imaginations and create new ones. Beginning with the concept of plate tectonics the development of geosciences accelerates remarkebly. Important milestones of that way were the ocean and continental drilling programs and the large national and international geophysical transects. Now geophysics is facing us with exciting new data - the mechanism of subduction is much more complicate and works for much greater depths than we thought yesterday. These and many other unmentioned facts are the challenge of up to date geosccientific high pressure research. The task forces new definitions what petrophysics and petrology is. From the experience of high pressure research the paper attempts to asks and answer some questions what laboratory data can do and where the limits are. What is the potential of what parameter? What should be measured yet? The paper is directed to all who are interested in geology, physics and technology in the same way.

THE INFLUENCE OF HYDROSTATIC PRESSURE ON ELASTIC AND THERMAL PROPERTIES

H.J. Müller, U. Seipold (GeoForschungsZentrum Potsdam, Telegrafenberg A17, 14473 Potsdam, Germany)
P.Tuisku (University of Oulu, FIN-90570 Oulu,Finland)
A. Korja (Geological Survey of Sweden, S-75236 Uppsala, Sweden)
T. Korja (University of Uppsala, S-75236 Uppsala, Sweden)

Elastic wave velocities and thermal transport parameters were measured for a collection of granulites sampled in northern Finland. The investigations were carried out under hydrostatic pressure up to 500 respectively 1000 MPa. The application of high pressure allowed us to vary the size of pores and cracks in the samples. They determine the petrophysical properties mainly in the low pressure range. It was found that especially in the initial range elastic and thermal properties react in a very different manner on high pressure. This means that pores and cracks also have different influence on elastic and thermal parameters.

FORMATION OF TEXTURIZED ROCKS WITH PIEZOELECTRIC PROPERTIES

A.N.Nikitin (Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia)
T.I. Ivankina (Teacher's Training University, Lenin prospect, 125, 300026 Tula, Russia)

A large of quartz rock samples were chosen to investigate the piezoelectric active rocks. The texture analysis of rock samples was carried out at the NSHR neutron diffractometer at the pulsed reactor IBR-2 of the JINR, Dubna. The piezoelectric effect was measured by the electrometric method using a point movable electrode following the acoustic excitation of the sample. The experimental data permits to characterize the piezoelectric activity of rock samples as a result of lattice preferred orientation, and allows conclusions about some peculiarities of the processes and mechanisms leading to the formation of piezoelectric active rocks with crystallographic textures. Three practicable mechanisms are suggested.

Properties of rock salt at isostatic and deformation conditions

T. Popp and H. Kern (Mineralogisch-Petrographisches Institut, Olshausenstr.40, 24098 Kiel, Germany)

Defining quantitative criteria delineating onset of dilatancy in rock salt is of vital importance for the design and safety analysis of underground cavities. Combined ultrasonic P and S wave velocity and permeability measurements were performed on natural rock salt samples at iso-static and deformation conditions (creep-rate or stress controlled). The two sets of data were used to infer relationships between crack density parameters calculated from the elastic wave velocities and the directly measured pore space parameters such as gas-permeability and porosity. In a number of samples exhibiting specific petrophysical and lithological characteristics the initial gas permeability was found to be effectively zero. In that case, gas permeability measured during the deformation experiment is directly correlated with dilatancy.

In samples exhibiting significant initial permeability, isostatic loading gives rise to a permeability decrease and a coeval velocity increase, basically as a result of a pressure-induced, largely irreversible closure ("healing") of pore space. Subssequent deformation causes an opening of pore space corresponding to a permeability increase of several orders and a wave velocity decrease of around 10%. The variation of the measured petropysical parameters provides the basis for the determination of the „dilatancy boundary" between the dilatant and compressive stress domains as a function of confining pressure.

THERMAL CONDUCTIVITY MODELS FOR N-PHASE SYSTEMS

Daniel Pribnow, NLfB-GGA, Stilleweg 2, D-30655 Hannover, dan.pribnow@bgr.de
Bernd Troschke & Hans Burkhardt, Technische Universität Berlin, Fachgebiet Angewandte Geophysik, Ackerstr. 71-76, D-13355 Berlin, troschke@bg.tu-berlin.de

Various models have been suggested to describe the thermal conductivity of n-phase systems. The geometric mean model, the layered model and the dispersion model are most practical because no structural information is required. The rock matrix conductivity can be determined with these models for three different systems: a) drill-cutting/water mixtures (n=2), b) porous media (n=2), and c) multi-mineral rocks (n is the number of rock-forming minerals).

These models are tested for crystalline and sedimentary rocks. Cores were measured intact, ground to cutting-size pieces, and the matrix conductivity was determined from measurements on these fragments (case a). The 2-phase models were also varified for sediments with known porosity (case b). For KTB rocks, complete mineral composition data are available to test n-phase models (case c).

Different structural characteristics of these systems require different models. However, in general and despite the lack of a physical argument, the geometric mean model provides the best agreement between measured and calculated values.

The validity of all models is strongly restricted to the constrast of the n thermal conductivity values in the system. 2-phase models, e.g., developed for water-saturated rocks (contrast < 10) are not valid for air-dry samples (constrast > 50).

AN EXPERIMENTAL STUDY OF TRANSPORT PROPERTIES OF POROUS ROCK SALT

E. Spangenberg, U. Spangenberg, C. Heindorf (GeoForschungsZentrum, Telegrafenberg A6, D 14473 Potsdam)

In most sedimentary sequences the rock salt layers consist of well cemented halite crystals with low or even negligible porosities. Therefore, not much research is carried out concerning the influence of porosity on the physical properties of rock salt.

However, the influences of higher intergranular porosities on the transport properties of rock salt are of interest for some technical applications and for a better understanding of salt diagenesis.

Combined measurement of electrical formation resistivity factor and brine permeability were performed on artificial rock salt samples with porosities between 5% and 45%. The measured permeability covers six and the formation resistivity factor nearly three orders of magnitude. A correlation of the formation resistivity factor with reciprocal porosity shows that it is possible to distinguish two ranges with a different behaviour. For the first range, „high porosity range", the porosity is determined by the arrangement of the salt grains. The other range, „low porosity range", represents the influence of salt deformation and creeping on porosity.

According to a capillary model the permeability shows a strong correlation with the formation resistivity factor.

Correlations to predict the mechanical properties of mudrocks from wireline logs and drill cuttings.

J.L. Urai, E. van Oort and W. van der Zee (Shell International Exploration and Production BV, PO Box 60, 2280AB Rijswijk, Netherlands.

A database of a wide range of properties of mudrocks from a wide range of compositions and depths was compiled and used to derive correlations which allow prediction of mechanical properties from subsurface data.

Young's modulus was found to be related to compressive strength by log(Eu) = -1.06 + 1.26*log(UCS), where UCS is unconfined compressive strength (MPa) and Eu is unconfined Youngs modulus (GPa). The well known correlation of swelling clay content and friction angle in clay rich soils was also found to exist for mudrocks, and is given by log(fi) = 1.54 - 0.0014*S where S is total surface area in m2/g and (fi) is Mohr-Coulomb friction angle in degrees. This relationship shows a wide scatter for surface areas in the range 200 - 400, consistent with a simple micromechanical model of a sand - clay mixture close to the percolation fraction for clays. As expected, cohesion does not correlate to surface area :two mudrocks with the same mineralogy but with different degree of lithification will have the same surface area but may have widely different cohesion.

A PETROLOGICAL MODEL OF THE CRUST IN THE TRANSYLVANIAN BASIN DERIVED FROM PHYSICAL PROPERTIES

Ş. Veliciu, (Geological Institute of Romania, Caransebes 1, 78344 Bucharest; Romania);

The theme of the present study starts from the inadequacies of the past interpretations from both geophysicists and geologists, which can be attributed to the attempt to isolate physical and petrologic parameters of the rocks from each other as uncoupled independent variables.
The procedure applied was as follows: firstly a given rock type was analysed by its mineralogical constitution and chemical composition in order to numerically characterise the mineral assemblage by its cationic packing index; then by laboratory measurements on physical and thermal parameters (heat conductivity, heat capacity, radiogenic heat generation, density, porosity, elastic parameters etc.) the systematic interrelations have been statistically established. Finally, the values obtained have been assigned to a certain geological cross-section for computer modelling by finite element method.
The described procedure was applied on rock samples collected from 51 different locations in the Transylvanian Basin area and a set of approximately 300 observations has been statistically processed. The selection of the rock samples has been based on two criteria: (1) the rocks should be representative for the constitution of the uppermost part of the lithosphere in the Transylvanian Basin region and (2) they should offer the possibility to investigate a variety of petrographic types ranging from the acid rocks to the basic ones.

SAMPLE LITHOLOGY DISCRIMINATION FROM ITS PHYSICAL PROPERTIES

M. Zamora, M. Bosch., W. Urama and G. Bienfait (Institut de Physique du Globe, 4 place Jussieu, 75252 Paris cedex 05, France)

Rocks are classified based in lithologic criteria such as mineralogic composition, texture and genesis. We examine the possibility of discriminating rock lithologic classes from measurements of the physical macroscopic properties of laboratory samples. Compresional and shear wave velocities, mass density, magnetic susceptibility, formation factor, surface conductivity and thermal conductivity have been mesured for more than a hundred rock samples. These samples include sedimentary, methamorphic and igneous rock. In particular granites, gabbros, basalts, sandstones, limestones, marble and other lithologies were represented. We submitted different combinations of these data to discriminant analysis, obtaining adequate classification of the lithologic families and adequate classification of the lithologic classes within a family. Our results favor the criteria that lithology can be predicted from rock physical macroscopic properties. Also, the analysis allow us to make a hierarchy of the more useful physical properties to discriminate the lithology in a particular geological environment.

LABORATORY MEASUREMENTS OF PHYSICAL PROPERTIES OF CAMPI FLEGREI (ITALY) VOLCANIC ROCKS AND THEIR RELATIONS TO FIELD DATA

B. Yven, M. Zamora (Institut de Physique du Globe, URA 734, 4, place Jussieu, 75252 Paris cedex 05, France)
and G. Sartoris (Dipartimento di Scienze Fisiche, Università di Napoli, Mostra d'Oltremare pad.19, 80125 Napoli, Italy)

We report the results of laboratory measurements of physical properties (porosity, permeability, thermal and electrical conductivities, velocity, attenuation and anisotropy of ultrasonic elastic waves) in rock samples coming from 5 geothermal wells reaching a maximun depth of 3 km, within the Campi Flegrei caldera located near the city of Naples, Italy. The studied samples are representative of products erupted during the last 35,000 years. The most frequent lithologies are tuffs, lavas and thermometamorphic rocks. In despite of high porosity of these samples, the permeability is low (~1 mD). The velocities (V_P=2.4-5.4 kms^{-1}, V_S=1.1-2.9 kms^{-1}) and the thermal conductivity (very low in the tuffs, ~0.1 $Wm^{-1}°C$) are correlated linearly to the formation factor. The surface electric conductivity (high, ~10^{-2} Sm^{-1}) is correlated exponentially to the formation factor. The mean velocities measured in laboratory overestimated less than 15% the sonic logs velocities. Laboratory electrical conductivity of studied samples, saturated with NaCl solution having equivalent *in situ* concentration, is between the two electrical conductivities deduced from LLD and LLS laterologs.

SE24/HS5.1 Estimation of transport parameters in unsaturated soils

Convener: Haverkamp, R.
Co-Convener: Durner, W.

IN-SITU ESTIMATION OF UNSATURATED SOIL HYDRAULIC PROPERTIES AND SPATIAL VARIABILITY

R. Angulo-Jaramillo, J.L. Thony, C. Zammit, J.P. Vandervaere, M. Vauclin, R. Haverkamp (Laboratoire d'étude des Transferts en Hydrologie et Environnement, UMR 5564 CNRS UJF INPG; LTHE, BP 53, F-38041 Genoble cedex, France; e-mail: angulo@img.fr), R. H. Cuenca, D. Gochis, and S. Kelly (Dept. of Bioresource Engineering, Oregon State University, Corvallis, OR 97331-3906, USA; e-mail: cuencarh@pandora.bre.orst.edu).

Tension disk infiltrometers have been used to investigate the statistical distributions of both hydraulic conductivity and capillary sorptivity in different hydrologic experiment programs (EFEDA (Spain), HAPEX/Sahel (Niger), and BOREAS (Canada)). The appropriate measurement strategy for soil water status and soil hydraulic properties in conjunction with regional experiments must recognize length scales and account for spatial variability of the soil processes and soil water conditions. Infiltration measurements provide a convenient tool for analyzing soil physical processes, complementary to short periods of the intensive measurements. Parameter estimations are obtained by using transient flow analysis of water infiltration. Significant attention has been paid to the fact that variations in soil properties are not necessarily random in space. This spatial structure may be taken into account in the data treatment by means of geostatistical concepts. Semivariogram analysis reinforces the need to consider partial correlation in models. Results (BOREAS experiment) suggest that hydraulic conductivity and sorptivity are best described by lognormal distributions.

TORTUOSITY COEFFICIENTS FOR STRUCTURED SOILS

U. Buczko (Innovationskolleg Bergbaufolgelandschaften, BTU Cottbus, PF 10 13 44, D-03013 Cottbus)
H.H. Gerke (Zentrum für Agrarlandschafts- und Landnutzungsforschung e.V., Institut für Bodenlandschaftsforschung, Eberswalder Str. 84, D-15374 Müncheberg)

Estimates of the tortuosity coefficient in transport models are often based on pore-size distributions, porosity, and relative phase saturation and calibrated using measured data of the relative effective diffusivity. Tortuosity models for variably-saturated porous media assume a unique relationship between relative saturation, porosity, and diffusion path length. For estimating tortuosity coefficients in structured soils, both the pore structure and the relative saturation can be different for the soil matrix and the fracture pore system. Here, we propose a tortuosity model for use in dual-porosity transport models and evaluate the analogy between tortuosity in diffusion- and permeability-models in order to transform transport parameters. A comparison of different tortuosity models with experimental data for different soils suggests that the proposed dual-porosity tortuosity model represents experimental diffusion data for structured soils better than conventional tortuosity-models for aggregated soils. For estimating the dual-porosity tortuosity coefficient, the volume proportion, porosities, phase saturations, and the slope of the water retention function for both pore systems are required. Diffusion and hydraulic conductivity data obtained from the same samples, however, show that tortuosity factors as defined in solute diffusion models are not simply comparable with tortuosity factors used in permeability models, although they are of the same form.

TRANSPORT PROPERTIES OF POROUS CRACKED ANISOTROPIC MEDIA

I.O. Bayuk and E.M. Chesnokov (Institute of Physics of the Earth, RAS, B. Gruzinskaya, 10, Moscow, Russia)

Methods for calculation of transport properties of porous cracked anisotropic media are developed. Various functions of cracks distribution over aspect ratio and angular orientation are considered. Tensor components of electrical (heat) conductivity and permeability are obtained. Comparison between elastic characteristics and permeability allows estimation of the permeability value.

POSSIBILITIES OF MAGNETIC RESONANCE IMAGING TECHNIQUES TO STUDY PREFERENTIAL FLOW IN NATURAL SOILS

M.Císlerová (CTU, Faculty of Civil Eng., Thákurova 7, 166 29 Prague 6, Czech R.)
L.D.Hall, M.H.G.Amin (Herchel Smith Laboratory for Medicinal Chemistry, University of Cambridge, Robinson Way, Cambridge, CB2 2PZ, UK)

For saturated porous media, the MR signal is dominated by relaxation at solid phase surfaces it means it is sensitive to the pore-size distribution. The relaxation rate in homogeneous region of porous material is proportional to the surface/volume ratio of the pore space. For soils the surface relaxation can often be very fast due to mineralogical heterogeneity from pore to pore. The largest inhomogeneities occur at the boundaries between liquid and solid, where the magnetic susceptibility of the material changes most significantly. Due to magnetic susceptibility contrast between grain material and pore fluid, the secondary unravelable magnetic field gradients can be created with unwanted deterioration of the image. In a consequence, the majority of soils which are in their nature heterogeneous are very difficult to be as thoroughly characterised as synthetic samples or pure materials. For natural porous rocks, both T_1 and T_2 relaxation times were found as characterised by multiexponential decays, the distribution of relaxation times being linearly related to the pore-size distribution. For fractured rocks it seems reliable that the preferential flow in larger pores where the effect of grain - pore interface is less, will be measured quantitatively in very near future (Derbyshire et al, 1994, Chen et al.1995). The data for dual porosity models could be developed then. To be able to gain this information also for soils, further improvements of hardware and measurement protocols have to take place.

Determining the hydraulic properties of a swelling soil by parameter estimation

P. Garnier. Laboratoire d'Hydrophysique, ORSTOM, 32, Avenue Henri Varagnat, 93143 Bondy Cedex, France

Most of the methods currently used to determine the hydraulic properties of swelling soils (i.e., the shrinkage curve, the moisture retention curve and the hydraulic conductivity curve) tend to be time-consuming because they require measurements of several different parameters (either in separate experiments or by using very expensive equipment). We propose a simple evaporation experiment to simultaneously determine all three soil hydraulic properties. We illustrate the use of the method with samples of a vertisol from the Senegal River valley. The shrinkage curve, $e(\vartheta)$, is determined during the experiment by horizontal and vertical linear deformation measurements, while an inverse parameter estimation method is used to determine the retention curve, $h(\vartheta)$, and the hydraulic conductivity curve, $K(\vartheta)$. This inverse method relies on a water flow model which takes into account the three-dimensional and anisotropic deformation of the soil. In order to assess the reliability of the estimated parameter values, we compared the results with those obtained by a multistep outflow experiment. A good agreement was found between the results of the different procedures. Then, the sensitivity of the method to the deformation was analyzed. In the soil investigated, the inverse method does not seem to require the use of a water flow model that takes into account deformation. However, a correction for deformation is needed if the characteristic functions are sought in terms of the volumetric water content.

SORPTIVITY MEASUREMENTS OF CLAY SOIL AGGREGATES UNDER DIFFERENT WATER CONTENTS

R. Greco, (Department of Civil Engineering, Second University of Napoli, al Casa dell'Annunziata, via Roma 29, 80031 Aversa (CE), Italy)
R. F. A. Hendriks (DLO Winand Staring Centre for Integrated Land, Soil and Water Research, P.O. Box 125, NL-6700 AC, Wageningen, Netherlands)

Characterization of the relationship between initial water content and aggregate sorptivity is helpful in modelling infiltration and transport in cracking clay soils. Therefore, a recently proposed sorptivity measurement technique for dry peds has been extended to various initial water contents. Experimental results for soil profiles from sites in Italy and the Netherlands have been compared with a commonly used sorptivity approximation based on soil hydraulic functions. The approximation gave realistic estimations for the sorptivity of some, but not for all the investigated horizons. Therefore, the easy and rapid measurement technique used here can be helpful in order to obtain realistic values for clay ped sorptivity as a parameter of a physically based infiltration model.

IDENTIFICATION OF NONLINEAR SORPTION ISOTHERMS BY SOIL COLUMN BREAKTHROUGH EXPERIMENTS

B. Igler and P. Knabner (Institute for Applied Mathematics, University of Erlangen, Germany)
K.-U. Totsche (Department of Soil Science, University of Bayreuth, Germany)

We consider the dispersive-advective transport of dissolved chemicals which undergo possibly nonlinear equilibrium and nonequilibrium sorption to the soil. The sorption mechanism is described by kinetic rate functions which are usually modelled by kinetic rate coefficients and sorption isotherms. These are to be identified by soil column breakthrough experiments.
It is crucial to set up experiments that lead to unique identifications of the unknown isotherms. It is shown that this condition is satisfied by outflow measurements which are obtained in soil column breakthrough experiments and that the minimum of an appropriate output least squares functional solves the identification problem.
A numerical scheme that is based on the output least squares method has been developed and implemented. The gradient that occurs in each optimization step can be efficiently computed by solving the discrete adjoint problem. The application of a parametrization which incorporates a multi-scale concept substantially accelerates and stabilizes the optimization process. Experimental and numerical results are presented.

WATER RETENTION CHARACTERISTICS AND PARTICLE-SIZE DISTRIBUTIONS OF FINNISH FOREST SOILS

M. Jauhiainen, T. Karvonen and P. Vakkilainen (Laboratory of Water Resources Engineering, Helsinki University of Technology, Tietotie 1, FIN-02150 Espoo, Finland)

Some relationships exist between soil texture and the unsaturated soil hydraulic properties albeit no general relationship has yet been identified. Andersson's (1990) model with a mathematical sturucture was used to describe the water retention and cumulative particle- size distributions of Finnish forest soils. Andersson's model was compared with van Genuchten-like models. Profiles (54) for the data were taken from coniferous stands. In each profile samples (216) were taken from four horizons in order to determine water contents at pF-values 0, 1, 1.5, 1.8, 2, 3 and 4.2 and particle-size analyses.

IDENTIFICATION OF SOIL PARAMETERS USING INVERSE METHOD

J. Jørgensen and F.-X. Le-Dimet (Laboratoire de modelisation et calcul, INPG-UJF-CNRS (URA 397), BP 53, 38041 Grenoble Cedex 9, France)
R. Haverkamp (Laboratoire des transferts en Hydrologie et Enviroment, UMR 5564-CNRS-U JF-INPG, BP 53, 38041 Grenoble Cedex 9, France)
G. Tuborg (Department of applied experimental irreversible fluid-mechanics, FBS-UJ T-CBG, BC 5700-8004, Hellerup, Denmark)

When dealing with large scale soil water transfer problems using aggregation of the Richards' equation, the traditional estimation of the required soil parameters cannot be applied for the hydraulic soil hydraulic characterization over the whole area. Thus, we focus this work on the parameter estimation from measurements of cumulative infiltration (an easily accessible integral property for which analytical expressions exists) by solving the inverse problem which consists of finding parameters that yield an infiltration profile optimally close to the measurements. While parameters like K_s and S_+ are easily identified, the shape parameter β, having a much smaller effect on the infiltration curve, is generally more troublesome. Experiments were performed with the initial conductivity set equal to zero, since the algorithm was unable to identify this parameter. But further investigations justify this behavior, suggesting that initial conductivity is defined by the 3 parameters already identified. The results thus imply that cumulative infiltration is uniquely defined by only 3 parameters and that the developed method, with a slight reformulation of the problem, clearly is able to identify these.

TRACER TRANSPORT EXPERIMENTS IN A GLASS-BEAD POROUS MEDIUM FOR ESTIMATING THE DEPENDENCE OF DISPERSION COEFFICIENT ON WATER SATURATION

K. Joswig, Institute of Water Resources and Hydraulic Engineering, Technical University Berlin, Germany
S. Maciejewski, Institute of Hydroengineering, Polish Academy of Science, Gdansk, Poland
G. Nuetzmann , Institute of Freshwater and Fish Ecology, Berlin, Germany

Changes in salt concentration with time were measured inside the uniform unsaturated glass beads column of length 100 cm and diameter 20.6 cm, that was leached at steady infiltration rates with solution of sodium chloride. Water content was measured at three depth using TDR-probes. By using different infiltration rates various moisture contents were available. Salt concentration was measured at two depths in three points of each cross section using platinum probes. Observed salt distributions were used to determine the dispersion coefficient. Analysis of experimental results allowed to recognize the mechanism of transport phenomena in porous media and gave some ideas concerning the measurement method. The dispersivity was found to increase with decreasing water content, from 0.065 cm for saturated medium to 0.75 cm for water content of 0.19 cm^3cm^{-3}, and to 1.5 cm for water content of 0.1 cm^3cm^{-3}. The breakthrough curves showed that the increase of solute mixing, with the decrease of water content, was caused by growth of flow velocities fluctuations for different path ways. It was pointed out in the paper, that the measurement of tracer concentration in one point gave local information about the solute transport in unknown path way. It is necessary to determine the mean concentration for the Representative Elementary Area.

ASSESSING TIME INVARIANCE OF PREFERENTIAL FLOW IN SMALL SOIL COLUMNS

S.K. Kamra, B. Lennartz (Institut für Wasserwirtschaft und Landschaftsökologie, Olshausenstr. 40, 24118 Kiel, Germany)

Displacement studies on bromide leaching under unsaturated steady state water flow conditions were conducted in two consecutive tests in 24 undisturbed soil columns (5.7 cm in diameter and 10 cm long) collected at a uniform grid from a loamy sand soil. There was large variability in the shapes of breakthrough curves (BTCs) of different columns during both tests including appearance of preferential flow features like early breakthrough and increased tailing in some columns. In principle, the preferential and non- preferential shapes of individual BTCs were maintained in two tests despite variations in water fluxes, flow velocities, pulse size and test durations. The field-average concentrations, computed as the arithmetic mean of individual columns, displayed double peak behaviour during both tests to reflect the effect of preferential flow. Transport parameters (retardation factor, R, and dispersion coefficients, D), of BTCs of both tests were highly correlated when all columns were considered; no definite correlation, however, existed amongst parameters of preferential and non- preferential flow columns considered separately. The consistency and time invariance of overall results of two tests suggest that the preferential flow features might be an strong intrinsic property of the soil under consideration which could be detected even in small columns.

LAECHING OUT OF A LARGE LYSIMETER — COMPARISON OF RETENTIVITY FUNCTIONS

M. Klein and M. Matthies (Institute of Environmental Systems Research, University of Osnabrueck, D-49069 Osnabrueck, Germany)

The soil water characteristic curve (SWCC), which is the relation between water content θ and soil suction h, masters the hydraulic properties of the porous medium soil. Because of capillarity it is related to the pore size distribution (PSD) and determines the unsaturated conductivity.
Lots of functions are proposed to fit as few parameters of $h(\theta)$ to measured points of the SWCC as necessary for accuracy and flexibility. Among these the function by VAN GENUCHTEN, and its refinement by FREDLUND are analyzed with respect to parameter sensitivity and impact on the derived conductivity functions. Furthermore a doubled VAN GENUCHTEN function is tried, in order to represent the incedence of macropores by a bimodal PSD.
The feasibility for environmental modelling of these approaches is compared by simulating daily leaching out of a lysimeter. The grass covered lysimeter at St. Arnold, North-West Germany, has a surface area of 400 m^2. It is filled with a podsolic soil and drained at 3.50 m depth. SWCC measurements have been performed at 8 suctions of soil samples from 5 different depths. The simulation model ARNOLDL bases on the Richards equation and the Penman evapotranspiration with empirical crop coefficients. Adapting the SWCC to the soil sample measurements, the model is calibrated by fitting the saturated conductivity to agreement of modelled and measured leaching data.

CALIBRATION OF A DUAL-POROSITY MODEL USING SOIL COLUMN AND FIELD DATA

M. Köhne, S. Meyer-Windel (Institut für Wasserwirtschaft und Landschaftökologie, Univ. Kiel, Olshausenstr. 40, D-24118 Kiel)
H. H. Gerke (Institut für Bodenlandschaftsforschung, Zentrum für Agrarlandschafts- und Landnutzungsfordschung (ZALF) e. V., Eberswalder Str. 84, 15374 Müncheberg

Dual-porosity models are designed to simulate preferential solute transport through structured soils. Problems with the application of mechanistic dual-porosity models arise from the independent determination of the large number of model parameters that are required. In this study, we consider water flow and non-reactive tracer transport in undisturbed soil columns as well as in an 0.5 ha agricultural catchment. The parameters of the flow model are independently evaluated by fitting dual retention and conductivity functions simultaneously to data of standard soil hydraulic measurements. The dispersion length for solute transport in the matrix pore system is obtained by steady-state soil column experiments. Mass transfer parameters, such as the characteristic half-width and the geometry of the matrix are estimated from soil profile observations. The hydraulic conductivity and the effective diffusion coefficient at the matrix/fracture interface, are calibrated by fitting simulation results for water movement and solute transport to measurement data obtained by soil column and field tracer experiments.

Spatial Variability of Soil Water and Nitrate of the Ground Moraine in Northeast Germany

S. Kofalk & G. Wessolek, Inst. of Ecology and Biology, Dept. Soil Science, TU Berlin, Salzufer 12, D-10587 Berlin

The Ground Moraine of Northeast Germany is characterized by small scaled spatial structures. The research was aimed at studying the structures and the effects of varying relief conditions and soil physical properties on soil water dynamics and nitrogen supply.
On various relief-positions the nitrogen status was researched at different times. The water potential, soil moisture and regularly soil hydraulic functions were determined. Field measurements were used to calculate the waterbudget components. The results show high differences in the ETI (mm/d) in one field. They are caused by the soil and relief conditions. In simulations with a two dimensional water model, the slope and exposition for three typical soils were considered. It could be shown that the seepage varies up to 20% within one soil unit. Long term simulations of the actual evapotranspiration and seepage show ranging seepages in the field from 54 up to 100 mm/a for the whole area. Histograms and the normal distributions of mineralic N pools for the sampling-time show a high variability: The CV ranges from 38 to 69 %. The CV varies in single positions in the average from 36 to 47%. The nitrate supply at the bottom is generally higher than at other slope positions.The influence of the relief can even be found by analyzing datasets with geostatistical methods. Empirical semi-variograms in show ranges of 10 m for the nitrate-pool and a typical "hole-effect". The morphological structures result in specific nitrate-pools in the same field.

CONE PENETRATION TEST METHOD FOR K(h) DETERMINATION

M. F. Leonard and M. M. Gribb (Dept. of Civil and Environmental Engineering, University of South Carolina, Columbia South Carolina, USA, 29208)
J. Simunek (US Salinity Laboratory, Riverside California, USA, 92507)

Effective clean up of contaminated sites requires characterization of impacted soils. In many cases this includes unsaturated soils. The hydraulic conductivity of unsaturated soil, K(h), is important for remedial design and accurate prediction of the movement of water-borne contaminants to ground water. A modified cone penetrometer has been designed for measuring K(h) in situ. The advantage of this tool is that it does not produce soil cuttings and it may be applied up to 30 m below ground surface. The device injects water into the subsurface while tensiometer rings measure increasing pore water pressures in the soil. Flow data are logged continuously with a computer. The data from short tests (5 - 10 min) are analyzed to obtain the van Genuchten parameters for K(h) using parameter estimation. The Levenberg-Marquardt optimization method is used to minimize an objective function expressing the differences between measured and numerically-predicted flow responses. HYDRUS-2D, a variably saturated flow code, is used to predict the cumulative inflow volume and pressure increases for inclusion in the objective function. Inversions of field-scale laboratory test results are shown and compared to independently-measured parameters. These results suggest that the saturated hydraulic conductivity, K_s, may be found using this method. Refinement of the analysis is necessary to obtain the other parameters of interest. Implications for further development of this method are discussed.

TWO-DOMAIN ESTIMATION OF WATER FLOW IN MACROPORE SOIL

L. Lichner (Institute of Hydrology SAS, Racianska 75, 83008 Bratislava, Slovakia)

A nuclear tracer technique is a promising tool for detailed investigation of water flow and solute transport in the unsaturated zone of soil. After infiltration and redistribution of the nuclear tracer solution, well detectable infiltration front in the soil matrix is formed. Additional infiltration of the non-tagged water results in a displacement of that front which is dependent upon the hydraulic properties of both macropore and matrix domains. Considering, for the sake of simplicity, a soil without macropores and the piston flow in it, the cumulative infiltration I results in the displacement I/n_{ef} of the front, where $n_{ef} = \Theta_s - \Theta_r$ is the effective porosity, Θ_s is the saturated water content, and Θ_r is the residual water content of that soil. In a soil with two-domain flow the same cumulative infiltration I results in an infiltration front displacement $h < I/n_{ef}$ in the matrix domain. In this case, $I = I_m + I_h$, where $I_m = I - h.n_{ef} - n_m)$ is the cumulative infiltration into macropores, $I_h = h.n_{ef} - n_m)$ is the cumulative infiltration into matrix, and n_m is the macroporosity. In this way, an estimation of macropore flow in the clay loam soil ($n_{ef} - n_m \approx 0.3$) was made, utilizing the results of the 1993-96 tracer experiments performed at the Experimental Station of the Research Institute of Irrigation in Most. The macropore flow was of about 49 % of the total flow in the barley field in the 1993 experiment, 19 % in the maize field in the 1995 experiment, and 53 % in the no-tilled soil covered with grass in the 1996 experiment. It can be seen that the warm and rainless second half of April 1993 resulted in nearly as high macropore flow in the barley field as that in the no-tilled soil.

AUTOMATIZED INSTRUMENTATION FOR WATER FLOW AND SOLUTE TRANSPORT OBSERVATION BY THROUGH-THE-WALL TECHNIQUE

M. Šir (Institute of Hydrodynamics, Academy of Sciences of the Czech Republic, Experimental basis Nový Dvůr, 38472 Zdikov, Czech Republic)
E. Lichner (Institute of Hydrology, Slovak Academy of Sciences, Račianska 75, P.O. Box 94, 83008 Bratislava 38, Slovakia)
J. Fiedler (ECO-Electronics, Grünwaldova 7, České Budějovice, Czech Republic)

In the through-the-wall measurement technique, a radioactive tracer is monitored without any disturbance as it flows past the dry-access observation well. Two types of measurements can be obtained: concentration distribution over time at the preselected elevation, and concentration distribution over depth. The measured concentration may be viewed as the flow-weighted concentration [Moltyaner, 1987]. The automatized instrumentation, built up by the ECO-Electronics, makes both types of in situ measurements possible during small-scale solute transport experiments in which an investigated solute is replaced by the gamma-emitting tracer with similar physico-chemical properties. The measurements are rapid, non destructive, able to locate heterogeneities in field soils, and do not influence solute transport. Due to very small dose and short halflife of the tracer they are not harmful to the environment.

CRACKED SOILS IN THE NOPEX AREA : THE INFLUENCE OF THE SOIL CRACKS ON THE INFILTRATION PROCESS

V. Novák, I. Žaludná (Institute of Hydrology, Slovak Academy of Sciences, Račianska 75, P.O.Box 94, 830 08 Bratislava, Slovak Republic)

Flat NOPEX area in its lover part is covered by a heavy clayey soils with cracks forming during the dry part of the vegetation period.It was recognized, that soil cracks can substantionally intensify the infiltration process. Soil cracks formation was studied at two agricultural sites (Lovsta and Marsta of the NOPEX area, near Uppsala, Sweden). The following soil characteristics were estimated at both sites: 1) relations between cracks porosity P_c and soil water content w, ($P_c = f(w)$), 2) specific cracks area on a soil surface A_c, and 3) length of cracks circumference on a soil surface L_c . Using the above mentioned soil cracks characteristics, the specific volume of cracks V_c (volume of cracks related to one square meter of soil surface) as a function of depth below the soil surface z was estimated, as well as the specific cracks surface S_c . Volume of cracks V_c (z) is an additional volume for precipitations accumulation, while cracks surface $S_c(z)$ - when filled-can increase the infiltration surface. The estimated specific total volumes of cracks were V_{c1} = 3.6 cm , V_{c2} = 2.7 cm at Lovsta site on May 30,1994, (CFE1) for soil covered by rye canopy. Aditional infiltration surfaces of cracks were S_{c1} = 5.9 m^2 and S_{c2} = 4.8 m^2. It means that, under given circumstances, the soil cracks can contain water layer of 36 and 27 mm and infiltration surface can be increased by up to 5,9 and 7 or 4.8 times, depending on depth of the filled part of soil cracks.

INVERSE MODELLING TECHNIQUES FOR DETERMINING HYDRAULIC PROPERTIES OF POROUS MEDIA BY TRANSIENT OUTFLOW METHODS

G. Nuetzmann , Institute of Freshwater and Fish Ecology, Berlin, Germany
M. Thiele, Institute of Freshwater and Fish Ecology, Berlin, Germany
S. Maciejewski, Institute of Hydroengineering, Gdansk, Poland
K. Joswig, Institute of Water Resources and Hydraulic Engineering, Technical University Berlin, Germany

A series of multistep outflow experiments were carried out to identify the unsaturated hydraulic properties of two homogeneous porous media (glass beads and sand). As it was pointed out by Kool and Parker (1987) long soil columns were used to achieve the desired resolution of the parameter identification problem. Because of the sharp fronts of water content decrease during these experiments the hydraulic functions are assumed to be represented by the complete van Genuchten - Mualem closed-form expressions with variable coefficients α, n, m and θ_r. The values of θ_s and K_s were measured directly. The inverse modelling technique consists of two steps: computation of the response surfaces as initial estimation and a optimization of the parameters using a numerical model and the Levenberg-Marquardt-scheme. A sensitivity analysis with respect to α, n and m shows, that conditions of local identifiability are satisfied if exclusively the measurements of water content in the column are considered. Additionally the cumulative outflow is necessary to check the mass balance of the numerical simulation. For both porous media good estimations can be achieved and the resulting hydraulic functions were used to verify the model with respect to other drainage experiments.

IMAGING FLUID FLOW IN UNDISTURBED SOIL USING ELECTRICAL RESISTIVITY TOMOG RAPHY

P.A. Olsen (Department of Soil and Water Sciences, The Norwegian Agricultural Unive rsity,1432 Aas, Norway)
A.M. Binley, S. Henry-Poulter (Center for Reasearch on Environmental Systems and Statistics, Institute of Biological and Environmental Sciences, Lancaster University, Lancas ter LA1 4YQ, England)

Soil structure has a significant impact on fluid flow. There is thus a need for non destructive measurements which provide spatial information of properties as soil moisture storage, solute concentration and flow velocities. Electrical Resistivity Tomography (ERT) provides the spatial distribution of internal bulk electrical resistivities in a vessel given measurements of the transfer resistances between electrodes on the circumference of the vessel. Using non-linear inverse method a 3-dimensional image of the electrical resistivity distribution is obtained. By applying a suitable electrolytic tracer to soils the change in bulk electrical resistivity can be interpreted as a change in the fluid conductivity. Images can be developed as a series of time slices thus revealing the pathways of the tracer as it moves through the soil core. This then allows some determination of solute breakthrough curves at many voxels within the soil core. Such results are presented here from a solute tracer study under steady state unsaturated flow. We observed that different soils responded differently depending on the internal structure.

DIELECTRIC CHARACTERIZATION OF BENTONITE AS A FUNCTION OF FREQUENCY, TEMPERATURE AND VOLUMETRIC WATER CONTENT

B. Oswald, H.R. Benedickter and W. Bächtold (Laboratory for Electromagnetic Fields and Microwave Electronics, Swiss Federal Institute of Technology, Zürich)
H. Flühler (Institute of Terrestrial Ecology, Soil Physics, Swiss Federal Institute of Technology, Zürich)
P. Marschall (National Cooperation for the Disposal of Radioactive Waste - NAGRA, Wettingen, Switzerland)

We report laboratory measurements of the complex valued relative permittivity $\epsilon_r = \epsilon'_r - j\epsilon''_r$ of montmorillonitic bentonite of hydrothermal origin from volcanic rocks from the *Serrata de Nijar* in the *Cabo de Gata* area (Almería, Spain). The data are parameterized by frequency f, temperature T and volumetric water content θ_{vol}. The geophysical characterization of potential candidates for nuclear waste disposal requires, amongst other quantities, the precise knowledge of the spatial distribution of the volumetric water content in a bentonite barrier surrounding a waste container. Such information can be obtained by exploiting the strong correlation between the relative permittivity of bentonite and its volumetric water content. In reality temperature T also varies and therefore we must consider this quantity as a parameter in the laboratory measurements. If in the field experiment time domain methods are used then it is important to remember that a TDR signal is a mixture of frequencies and therefore the frequency dependence of ϵ_r must also be known *a priori*.

DISCRETE MULTIPHASE FLOW SIMULATION IN POROUS MEDIA

R. A. Pieritz, J.P. Laurent
LTHE - Lab. D'Étude des Transferts en Hydrologie et Environnement
UMR5564/CNRS - INPG - UJF
BP53 - 38041 - Grenoble Cedex 09 - FRANCE

The interpretation and modelling of multiphase flow and retention properties of porous media must take into account the complexity of the internal geometry of the microscopic channels. Unsaturated flow in subsurface hydrology is a specific case of multiphase flow in porous media. It is the case when the porous space of a soil is filled by water and air, which are the two fluid phases the most usually present in the natural environment. Displacement simulations in realistic pore networks (2D/3D) are presented for cases where capillarity controls fluid motion and spatial distributions. With discrete geometry tools, the real network is reduced to an integer radius map called "background distance map". A local transform allows a flow path "skeleton" to be extracted. In equilibrium conditions, a set of radii, connected to the injection (or drainage) boundaries, are detected in this topologic representation. The skeleton inverse transform is then applied to determine the flow geometry. Complex displacement sequences, involving partial or total imbibition and drainage, can be simulated that way. Resulting equilibrium fluid distributions are used to estimate transport properties for each phase. The corresponding algorithm allows studying the irreducible wetting phase saturation or fractured media.

DISCONTINUOS PHENOMENA IN SOIL WATER FLOW

J. Pražák (Institute of Thermomechanics ASCR, Dolejškova 5, 18200 Praha, Czech Republic)
M. Šír and M. Tesař (Institute of Hydrodynamics ASCR, Experimental Basis Nový Dvůr 31, 38472 Zdíkov, Czech Republic)
L. Lichner (Institute of Hydrology SAS, Račianská 75, 83008 Bratislava, Slovakia)

Within the scope of a hydrological program launched in 1983 in the Šumava Mts., the soil water regime is measured by water tensiometers in correlation with the rainfall and evapotranspiration data. In certain periods, the soil water regime could be explained only by assuming an irregularly oscillating outflow of soil water into lower horizons. In these situations a big volume of water flows through the soil; therefore, on the hydrological scale, this phenomenon forms a great part of the outflow from a watershed. In order to deeper elucidate the soil water movement, some nuclear tracer experiments in the Šumava Mts. - the mean elevation 800 m a. s. l. (Czech Republic) and in the Danubian Lowland - the mean elevation 100 m a. s. l. (Slovakia) were arranged. The main purpose of our experiments was to reproduce the phenomena observed in situ under controlled conditions: 1. to stabilize water sprayed over the soil surface in the soil profile, 2. to loosen stabilized water, to generate outflow oscillations. The main conclusion is that the soil water movement is essentially nonhomogeneous and instable.

PARAMETER ESTIMATION OF UNSATURATED SOIL HYDRAULIC FUNCTIONS FROM EVAPORATION EXPERIMENTS

Alessandro Santini, Nunzio Romano (Institute of Agricultural Hydraulics, University of Naples "Federico II", Italy)

A laboratory inverse method is developed for determining soil water retention and hydraulic conductivity functions simultaneously from an evaporation experiment using a parameter estimation technique. The unknown parameters in closed-form analytical expressions employed for describing soil hydraulic properties are estimated by a non-linear least-squares optimization problem which minimizes the deviations between the numerical solution of the transient flow process and the real system response measured during the evaporation experiment. Different analytical relations are used in this study to describe soil hydraulic properties. The transient water flow in soil is simulated by numerically solving the Richards equation with the appropriate initial and boundary conditions. The reliability of the proposed method is shown for different types of soils by comparing the estimated soil hydraulic properties with data points obtained via the instantaneous profile method, and by analyzing the effects of data error on parameter estimates. Additionally, parameter sensitivity analysis and computation of response surfaces address questions relating to problems of identifiability and uniqueness of the inverse solution.

ANALYSIS OF SOIL WATER RETENTION SPATIAL VARIABILITY USING PEDO-TRANSFER FUNCTIONS

Nunzio Romano and Alessandro Santini (Institute of Agricultural Hydraulics - University of Naples "Federico II", Italy)

The objective of this study was to evaluate some published pedo-transfer functions (PTFs) in the light of their ability to quantify the spatial structure and variability of soil water retention adequately. Measured data for testing were obtained from undisturbed soil samples taken from the uppermost layer of different soils along a 5-km transect with constant spacing of 50 m. Each sample was subjected to standard laboratory analyses to determine soil physical and chemical properties, whereas a sand-kaolin box and a membrane plate apparatus were used to measure soil water retention data points. For each sample, the retention data were fitted with van Genuchten's analytical relation. Dependence of fitted and PTF-estimated water retention characteristics on separation distance along the transect was examined using geostatistics and experimental semivariograms were described by a combination of pure nugget and spherical models. Overall, statistical analyses indicate that summary statistics and sample distributions of the PTF-estimated retention characteristics are very close to those of the fitted variables used as reference for comparison. Although the quality of kriged interpolations based on soil property data obtained by simplified methodologies still gives cause for concern, results show that the structure of spatial variability exhibited by the considered variables along the study transect is described well enough when using PTFs for determining soil water retention characteristics.

Water content profile estimation in porous media from spatial deconvolution of TDR waveforms measurements

Luiz A. Pereira dos Santos, Jean-Paul Laurent, Georges Vachaud and Jean-Louis Thony (Laboratoire d'etude des Transferts en Hydrologie et Environnement (Univ. J. Fourier - CNRS UMR 5564 - INPG), BP 53, 38041 GRENOBLE Cedex 9, FRANCE)

Until now the Time-Domain Reflectometry (TDR) technique has been mostly used to determine bulk water content of porous materials from the analysis of the transit time required for a microwave pulse to travel on a known length of transmission line. In this work, we propose a method of spatial deconvolution of TDR signals that will allow the direct estimation of water content profiles. This method is based upon the theory of reflection of electromagnetic waves in the case of inhomogeneously filled waveguides. An expression of the reflection coefficient was obtained based on the concept of distributed parameters using a circuit-analysis approach. The frequency domain analysis of TDR waveforms is used to link the data measurements with the theory. Preliminary results have been obtained for discontinuous profiles using glassbeads and demineralized water. This technique has since been applied directly in the field for soil-moisture profile determination. Part of this work was supported by a student grant from the CAPES Brazilian Finance Agency.

DETERMINATION OF HYDRAULIC PROPERTIES OF SOIL SAMPLES BY TRANSIENT FLOW EXPERIMENTS –DYNAMIC EFFECTS AND TIME SCALE DEPENDENCY

B. Schultze and W. Durner (Department of Hydrology, University of Bayreuth, D-95440 Bayreuth, Germany)

Inverse modeling of transient inflow/outflow experiments has become a widely used method to determine the hydraulic properties of undisturbed soil samples in a fast, accurate, and efficient manner. In the past there has been some concern on whether hydraulic properties of soils are of static and time-invariant nature, and thus independent of the imposed boundary conditions. We performed experiments where we imposed smooth changes in water pressure to the bottom end of undisturbed samples of a sandy soil. The observed cumulative outflow and backflow, as well as tensiometric potentials and water contents at two depths in the soil samples were continuously recorded and used in an inverse modeling procedure for the optimization of the hydraulic functions. By repeating the experiment with a varying speed of the pressure changes, the outflow and backflow process was forced to take place at different time scales. Our results indicate that transient water flow in undisturbed soil columns is not in accordance with the classical one-phase flow theory, as expressed by Richards equation with time-invariant retention and conductivity characteristics.

ESTIMATING UNSATURATED SOIL HYDRAULIC PROPERTIES FROM MULTIPLE TENSION DISC INFILTROMETER DATA

J. Šimůnek, D. Wang, and M. Th. van Genuchten (U.S. Salinity Laboratory, USDA, ARS, 450 W. Big Springs Road, Riverside, California 92507, USA)

In a previous study we showed that infiltration curves measured with a tension disc infiltrometer at one particular tension do not provide enough information to estimate van Genuchten's soil-hydraulic parameters by numerical inversion of the Richards equation for unsaturated flow. In this paper we analyze the use of infiltration curves obtained with the tension disc infiltrometer at several consecutive tensions to estimate soil hydraulic parameters. We also investigate if parameter identification can be improved by adding easily obtainable information, such as the final water content below the permeameter, or by using Wooding's [1968] analytical solution in combination with numerical inversion of the Richards equation. The study was carried out in the field using a disc permeameter with radius of 10 cm and consecutively applied tensions of -20, -10, and -3 cm. The average initial water content of the soil beneath the disc was 0.077 and the final water content below the disc was about 0.25, i.e., 0.12 lower than the saturated water content measured in the laboratory. Our parameter estimation procedure combined the Levenberg-Marquardt nonlinear parameter optimization method with the numerical model HYDRUS-2D for solving the variably-saturated flow equation. The soil hydraulic parameters obtained from the field disc permeameter experiments will be compared with retention data measured in the laboratory.

USER-FRIENDLY INTERFACE FOR HYDRUS-1D CODE IN WINDOWS ENVIRONMENT

J. Šimůnek and M. Th. van Genuchten (U.S. Salinity Laboratory, USDA, ARS, 450 W. Big Springs Road, Riverside, California 92507, USA)
M. Šejna (PC Progress, Prague, Czech Republic)

An interactive graphics-based software package HYDRUS-1D which was developed in support of the computer model HYDRUS 6.0, will be presented. HYDRUS-1D may be used to simulate one-dimensional variably-saturated water flow, heat transport, and movement of solutes involved in first-order decay reactions. HYDRUS uses the Richards equation for simulating variably-saturated flow and the Fickian-based convection-dispersion equation for both heat and solute transport. The water flow equation incorporates a sink term to account for water uptake by plant roots. Hysteresis in the soil hydraulic properties is accounted for by the model. The solute transport equations consider convective-dispersivetransport in the liquid phase, as well as diffusion in the gaseous phase. The transport equations also include provisions for nonlinear nonequilibrium reactions between the solid and liquid phases, linear equilibrium reactions between the liquid and gaseous phases, zero-order production, and first-order degradation reactions. HYDRUS was coupled with the Levenberg-Marquardt nonlinear parameter optimization method to estimate van Genuchten's soil hydraulic and solute transport parameters from transient water flow and solute transport experiments. The user interface includes data pre-processing and graphical presentation of the output results in a Microsoft Windows environments.

MEASUREMENT AND INTERPRETATION OF SATURATED HYDRAULIC CONDUCTIVITY IN THE FIELD CONDITIONS.

V. Štekauerová, J. Šútor and T. Šembera (Institute of Hydrology, Slovak Academy of Sciences, Račianska 75, P.O.Box 94, 830 08 Bratislava, Slovak Republic)

The measured saturated hydarulic conductivity of soils without macropores represents conductivities of soil matrix only. These values are useful for modelling of the soil water transport by mathematical models, which are based on the Richard's equation. However, saturated hydraulic conductivity measured in the field conditions, with a developed system of macropores, reflects more conductivity of the macropores. Both saturated hydarulic conductivities can differ and it is important to separate them. Presented contribution deals with values of the saturated hydraulic conductivity measured by Guelph permeameter (K_{GP}) and with values of the hydraulic conductivity measured by disc permeameter (K_{DP}) in the near saturated state (h_w = -1.7 cm). All measurements were made in 1 cubic meter of soil in 5 verticals and in 3 horizons. Each value K_{GP} and K_{DP} was measured in the same vertical direction. First, K_{GP} was measured in horizon z_1 = 30cm and then K_{DP} was measured in the same horizon (in the near saturated state). Then the same measurements were repeated in horizons z_2 = 70 cm and z_3 = 95 cm. The average rations K_{GP} / K_{DP} were: 10.9 in horizon 30 cm, 3.0 in horizont 70 cm, and 1.4 in horizont 95 cm.

UNCERTAINTIES IN EXPERIMENTAL ESTIMATION OF HYDRAULIC PROPERTIES IN UNSATURATED HETEROGENEOUS SOIL

A. Stodolovská[1], O. Wendroth[2] and M. Císlerová[1]
[1] CTU, Faculty of Civil Eng., Thákurova 7, 166 29 Prague 6, Czech Republic
[2] ZALF, Institute For Soil Landscape Research, Eberswalder Str. 84, 153 74 Münchenberg, Germany

Two different methods were used for determination of the hydraulic conductivity function and the soil water retention curve to find out the differences in measured θ(h) and K(h) and its propagation to the predicted K(h). The disk tension infiltrometer and the evaporation method were applied, in both methods, soil water pressure head was measured simultaneously. The undisturbed soil samples of coarse sandy loam were taken in Korkusova Hut (Czech Republic). This highly heterogeneous soil type (Cambisol) exhibits the preferential flow and the dependence of the saturated hydraulic conductivity on the initial soil water content. The unsaturated range near water saturation was of the main concern. From measured data the parameters of van Genuchten's analytical closed form expressions of retention curve were evaluated. Unsaturated hydraulic conductivities were calculated from water flux densities and hydraulic gradients. Average of upward water flux density was estimated from changes of water content in time. High sensitivity of unsaturated hydraulic conductivity values on negligible changes of hydraulic gradient leads to uncertainty in the soil hydraulic function determination. Results obtained for each of 6 soil samples are similar. The high degree of hysteresis is indicated in most of the cases. The study was performed in laboratories of ZALF in frame of joint cooperation.

SLOPING LYSIMETER RAINFALL-RUN-OFF EXPERIMENTS ON LOAMY SOILS

El Idrissi A., M. Vanclooster and E. Persoons (Unité de Génie Rural, Department of Environmental Sciences and Land Management, Place Croix du Sud 2, Boite 2, B-1348 Louvain-la-Neuve)

Heterogeneity complicates the determination of water transport properties in soils at different spatial scales. In addition, different boundary conditions may affect the flow domains participating to the water transport process. Therefore there is a need to develop experimental devices which enable to characterize flow properties at different temporal and spatial scales.

Within this study, an experimental device was developed to measure functional soil water balance terms (drainage, soil water storage and run-off) at the scale of a small plot subjected to variable boundary conditions. The experimental device consisted of a high quality indoor rainfall simulator and a $6m^2$ indoor sloping lysimeter. The lysimeter has a depth of 0.5 m. Functional balance terms such as soil water storage, soil water run-off , and drainage were measured for fourty unsteady state flow experiments. The experimental data were analyzed to quantify the effect of antecedent soil moisture and slope on total run-off. Future research envisage to combine physical rainfall-run-off and infiltration models with inverse modelling procedures to characterize the unsaturated flow properties at the scale of the plot subjected to different rainfall events.

MAGNETIC RESONANCE PROPERTIES OF WATER IN SOILS WITH VARYING SOIL WATER CONTENT AND VARIOUS COMPACTION

J. Votrubová[2] , M. Šanda[2], L. D. Hall[1], M.H.G.Amin[1] and M. Císlerová[2]
[1] HSLMC, University of Cambridge, Robinson Way, Cambridge, CB2 2PZ, UK
[2] CTU, Faculty of Civil Eng., Thákurova 7, 166 29 Prague 6, Czech Republic

A study of bulk NMR parameters (the longitudinal (T_1) and the transverse (T_2) relaxation times and the proton density (Mo)) of water in soils as obtained by 4 basic MRI protocols was conducted. The pulse sequences: single 90° pulse giving Mo(FID), single Spin Echo sequence with TE=2.9 ms giving Mo(SE), CPMG sequence giving T_2 and Mo(T_2) and Inversion Recovery sequence giving T_1 and Mo(T_1) were used. Two representative soils were chosen from both ends of the range of soil suitability for MRI: "good" fine sand (Hupselse Beek, Netherlands) and "bad" coarse sandy loam (Korkusova Hut, Czech Republic). For each soil 1 undisturbed and 4 disturbed samples of various bulk densities were examined. Each sample was scanned in 3-6 steps of different water content covering the whole range from the residual moisture to the saturation. Stretched exponential and 3 component exponential functions were used to fit the T_1 and T_2 relaxation. The fraction of amount of water visualized using each of MR methods was derived from the ratio of the acquired signal intensity (Mo) and the signal intensity produced by the equal amount of water, the part of the defined solution of D_2O+H_2O+$CuSO_4$. For all methods used, a relationship of NMR parameters to the water content and porosity is evident, the fine sand showing significantly clearer trends. Variations of Mo values determined by different MR methods are caused by very fast decay of the signal in soils and by the timing of pulse sequences in the research instrument used.

COMPARISON BETWEEN THE INSTANTANEOUS PROFIL METHOD AND THE MULTISTEP OUTFLOW METHOD FOR MEASURING THE UNSATURATED HYDRAULIC CONDUCTIVITY OF SOILS UNDER LABORATORY CONDITIONS

B. Wimmer, N. Rampazzo and W.E.H. Blum (Universitaet fuer Bodenkultur, Institut fuer Bodenforschung, Gregor Mendel-Str. 33, A-1180 Wien, Austria)

There is still a need for cheap, rapid but accurate methods for measuring the unsaturated hydraulic conductivity of soils as input for water and solute transport models and for obtaining its spatial variability. The multistep outflow method using pressure chambers and inverse modelling technique is a cheap and rapid method for determining the unsaturated hydraulic conductivity. In this study the multistep outflow method is compared to the instantaneous profile method using tensiometers and TDR probes. Soil cores were taken from a chernosem soil near Vienna (Austria) at different locations and 3 depths. The results of the two methods are in good agreement except for the samples in 60 cm depth where soil inhomogeneity might have a strong influence on the hydraulic properties. Additionally at three core samples both methods were applied simultaneously. Two of them showed similar hydraulic conductivity functions. The saturated hydraulic conductivity obtained as a fitting parameter of the multistep outflow method is not an accurate estimate compared to the field saturated hydraulic conductivity measured with the guelph permeameter method.

EFFECTS OF SOIL TYPE AND WATER FLUX ON SOLUTE TRANSPORT

J. Vanderborght, D. Mallants, J. Feyen (Institute for Land and Water Management, KULeuven, Vital Decosterstraat 102, B-3000 Leuven, Belgium)

Solute concentrations were monitored at six different depths using TDR in 1-m long 0.8-m i.d. lysimeters during breakthrough experiments. The lysimeters contained undisturbed soil monoliths taken from three different soil types: Plaggept, Hapludalf and Glossudalf. To investigate the effect of the water flux on the solute transport, the breakthrough experiments were repeated for two flow rates: 0.01 m/d and 0.005 m/d. Since solute concentrations were measured at several depths in the soil profile, the validity of two distinct solute transport processes to describe lysimeter-scale solute transport was investigated: (i) the stochastic-convective transport process (CLT model) assuming no mixing of solutes, and (ii) the convective-dispersive transport process (CDE model) assuming complete mixing of solutes. Solute transport in the Plaggept and Hapludalf soils was better described by the CLT model whereas the CDE model was more suited for the Glossudalf soil. Solute dispersion or solute transport heterogeneity was larger for the Plaggept and Hapludalf soils than for the Glossudalf soil. The parameters of the transport models depended largely on the applied water flow. In addition, the solute transport heterogeneity increased with increasing flow rate, especially in the Hapludalf soil. This was probably due to the activation of macropores for the higher flow rate.

EFFECT OF WATER CONTENT, SALINITY, SURFACE CONDUCTANCE, AND ION-MOBILITY ON ELECTRICAL CONDUCTION IN UNSATURATED SANDY SOILS

A.H. Weerts, W. Bouten (Landscape and Environmental Research Group, University of Amsterdam, Nieuwe Prinsengracht 130, 1018 VZ, Amsterdam)

Solute transport parameters of laboratory soil columns and field soils are more and more derived from experiments involving the measurement of the bulk-soil electrical-conductivity, σ_a (Sm^{-1}). Models that decribe σ_a as a function of soil-water conductivity, σ_w ($S\ m^{-1}$), water content, θ (m^3m^{-3}), and other soil parameters are used to obtain the total concentration of the soil solution. Samples of three sandy soils with different CEC (low/intermediate/high) were saturated with a NaCl-solution with salinities in the range of 0.01-1.0 Sm^{-1}. In addition, samples of the soil with intermediate CEC were saturated with a $CaCl_2$- and $(C_2H_5)_4NCl$-solution. Simultaneous measurements of the hysteric water-retention-curve and σ_a (with TDR) on all these samples were made. The aims of this study are (1) to test several models of σ_a as a function of θ, σ_w, CEC, and ion-mobility and (2) to study the effect of hysteresis on electrical conductivity in sandy soils.

RELATIONS BETWEEN HYDRAULIC SOIL CHARACTERISTIC PARAMETERS.

C. Zammit, R. Haverkamp, (Laboratoire des Transferts en Hydrologie et Environnement, UMR 5564 -CNRS-UJF-INPG, BP 53, 38041 Grenoble Cedex 9).

To describe water content transfer, in the unsaturated zone of soils, knowledge of the soil hydraulic properties is required. Different functional relationships can be chosen for the description of : a) the relation between volumetric water content (θ) and the soil water pressure (h) and b) the relation between volumetric water content (θ) and hydraulic conductivity (K). These relations have to obey constraints imposed by the use of the transfer equations such as Richard's equation. In a compilation of data concerning several hundreds of soil, including particle size distribution, h-(θ) and K-(θ), a parameter study is carried out to establish physically meaningfull relationships between soil properties (texture) and the transfer models. Since the soils in the database cover a wide range of soil types, taken mostly from the literature, it is possible to identify relevant shape parameters.
Results suggest that some relations between the shape parameters of the functional relationship of the hydraulic soil properties exist, and these relationships depend on the chosen functional.
The present soil catalogue will be available for interested researchers in this study.

SOIL POROUS MEDIUM STRUCTURE, UNSATURATED SOIL HYDRAULIC PROPERTIES AND WATER FLOW MODELS

A.M. Zeiliguer (Moscow State University of Environmental Engineering, Pryanishnikov Str. 19, 127550 Moscow, Russia)

The current interest of hydrology subsurface transport process modeling in the soil porous medium structure (SPMS) arises from the need to predict the model parameters in connection with static and dynamic of physicochemical soil state in function of soil solid phase and SPMS properties. This is especially the case of the unsaturated soil hydraulic properties relating the water flow (WF) models with simulated real process. Proposed approach is based in the identification one of elaborated SPMS models ("*textural*", "*structural*", "*aggregated*", "*swelling*", "*alkali*", "*gypso-calcareous*") forming a hierarchical system using the indicator soil parameters. These models describe the SPMS explicitly in the terms of specific volume of interconnected and subordinated subspaces of transport and dead-end pores. For each of these SPMS models WF model is associated applying the modified Richard's equation for transport pore subspaces and equilibrium equation between blocked air and compressing it water in dead-end pore subspace. The water retention curve of all subspaces is estimated from the SPMS properties and fitted by multi-Veibul's function. To predict the hydraulic conductivity of transport pore subspaces the Mualem's and Burdine's models are adapted. This approach to estimate the unsaturated soil hydraulic properties using the SPMS models was validated by laboratory and field experimental data of various soils of Bulgaria, Hungary, Uzbekiston, Russia, France and Switzerland.

SE25 Regional magnetic survey: data, models and charts

Convener: Hejda, P.
Co-Convener: Chiappini, M.

REGIONAL MAGNETIC SURVEY OF EGYPT: DATA,MODELS AND CHARTS.

F.M.AHMED(National Research Institute of Astronomy and Geophysics,Helwan,Cairo,Egypt)

The absolute Geomagnetic Field components of Egypt were measured at 10000 Points along all accessible roads of Egypt. The magnetic daily recordings of Misallat geomagnetic observatory were used to eliminate the daily variations to reduce the field abservations to the datum then to the epoch 1990.0

I somagnetic contour maps of the distribution of the geomagnetic field elements of Egypt are given.

FINAL RESULTS OF THE 1992.5 GEOMAGNETIC REPEAT STATION SURVEY ACROSS GERMANY: NORMAL FIELD MODEL AND ANOMALIES

A.Best (GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany) V.Auster (MAGSON, D-10318 Berlin, Germany), M.Beblo (Universitaet Muenchen, Geophysikalisches Observatorium, Ludwigshoehe 8, D-82256 Fuerstenfeldbruck, Germany), M.Gropius, Im Tale 10, D-20251 Hamburg. Germany), G.Schulz (Bundesamt fuer Seeschiffahrt und Hydrographie, Erdmagnetisches Observatorium, Am Olymp 13, D-21789 Wingst, Germany)

Many geomagnetic survey activities took place in the region of Germany. But unfortunately to different epochs and for different districts. Nevertheless it seems to be profitable to derive normal field models from different times. Final second-order models of the 1992.5 normal field over the area of Germany are represented, based on repeat station surveys carried out in 1964/65 and 1982 in the FRG, in 1990 in the former GDR and in 1992 across the reunited Germany.

PROBLEMS CONNECTED TO THE LARGE SCALE COMPOSITE MAGNETIC MAPS.THE NATIONAL GROUND GEOMAGNETIC MAP OF ROMANIA

Lucian Beşuţiu, The Geological Institute of Romania, Department of Geophysics

The paper deals with problems connected to the achievement of the national or international geomagnetic maps. Most of them can be performed as a composite map only, by using data related to various base stations and different geomagnetic epochs.
Important distortions of the regional geomagnetic anomalies, due to the secular variation (SV) of the geomagnetic field, are expected in such a case.
The case history of the national ground geomagnetic map of Romania is presented. SV distortions due to the datum shifts generated by the incorrect reduction to an unique geomagnetic epoch, improper normal geomagnetic field model, etc., are revealed by comparing the geomagnetic reference level of the map to the level provided by the base stations of the national network for SV studies. Following this procedure, differences up to more than 100 nT were pointed out.
The role of the national magnetic control network in the achievement of a consistent set of observational data is discussed.

CARACTERISTICS OF THE SECULAR VARIATION OF THE GEOMAGNETIC FIELD IN SOUTH-EAST EUROPE IN THE PERIOD 1858-1990, BASED ON REPEAT STATION NETWORK DATA.

T. Bicskei (Geomagnetic Institute,11306 Grocka,Yugoslavia)

At 50' s in most countries from mentioned area a repeat station network was established with a main task to explore the secular variation of the geomagnetic field. The geomagnetic measurments at this stations were made sistematically with well-defined time of repetition.
In this review the repeat station data are discussed in terms of internal secular and solar cycle related variations. Their geographical distribution is accounted for by magnetic and electric structure of the interior of the Earth. The effects of magnetic and electromagnetic induction caused by the solar cycle related variations were evaluated.

SPECTRAL AND TEMPORAL ANALYSIS OF THE ANNUAL MEANS OF MAGNETIC ELEMENTS AT SELECTED WORLD MAGNETIC OBSERVATORIES

T. Bicskei (Geomagnetic Institute,11306 Grocka,Yugoslavia)

The analysis of results of direct observations allows us to reveal most characteristic variations of the geomagnetic field and to suppose that secular variation spectrum is discrete. It includes variation with different periods.
The purpose of this analysis is to investigate the characteristic times and periodicities for different kinds of geomagnetic field changes.

SPACE-TIME STRUCTURE OF THE GEOMAGNETIC FIELD IN SOUTH-EAST EUROPE IN THE TIME INTERVAL 1850-1990

T. Bicskei
D. Popeskov
A. Haskic (all at: Geomagnetic institute, 11306 Grocka, Yugoslavia)

In the passed 140 years, within the area of countries from the south-eastern Europe during a different time-periods geomagnetic surveys of greater or smaller extent are made repeatedly.
For such a long time-period the secular change of the geomagnetic field has undergone a number of significant changes. The object of this analysis is to reveal the main features of field changes expressed in its space-time evolution.

SPATIAL AND TEMPORAL VARIATIONS OF GEOMAGNETIC FIELD IN SOUTH-EAST EUROPE IN THE PERIOD 1850-1990.

T. Bicskei (Geomagnetic Institute,11306 Grocka,Yugoslavia)

The secular variation is investigated by using results of the different magnetic surveys made in south-eastern Europe between 1850 and 1990.

GEOMAGNETIC FIELD ON THE TERRITORY OF THE CZECH REPUBLIC FOR THE PERIOD 1995.5 AND ITS SECULAR VARIATION

V. Bucha, I. Cupal, **P. Hejda** and J. Horáček (Geophysical Institute AS CR, Boční II, CZ-141 31 Praha 4, Czech Republic)

On the territory of Bohemia and Moravia the measurements of the vector of geomagnetic field (declination, inclination and total intensity) were carried out at 200 points of the 1st order in 1994 - 1996. All values were reduced to the epoch 1995.5 using data from the Geomagnetic Observatory Budkov and magnetic maps were derived by means of standard computer software. The comparison of recent measurements with older mapping for epochs 1978.5 and 1958.0 enabled to study regional anomalies of the geomagnetic secular changes on this territory.
Since the geomagnetic field varies non-linearly in time, a network of secular stations was established where repeated magnetic measurements were carried out since 1950 approximately every two years. These data, together with the annual mean values from Central European observatories, were used for derivation of the continuous model of secular variation on the territory of the Czech Republic. An attempt has been made in the forecasting the secular variation for 2 years. The model seems to fit with real observations up to 5 nT.

A COMPARISON OF SURFACE MAGNETIC DATA AND MAGSAT DATA OVER ITALY AND ITS SURROUNDING

P.Cantini, E. Pinna (Dipartimento Scienze della Terra, Università di Pisa, Italy)
I. Marson (D.I.N.M.A., Università di Trieste, Italy)

A new map of regional magnetic anomaly for Italian area has been derived from sea-level data on the basis of an improved definition of the Italian Magnetic Reference Field and its time change constrained by Aquila National Magnetic Observatory variation. A spectral analysis of the regional field shows a broad band of energy in the wavelength range 30-400 km, due to the presence of different crustal sources. The surface magnetic anomaly map shows poor consistency with the corresponding Magsat scalar anomaly map, whose power spectrum reveals long wavelength components in the range 200-1300 km, having origin in the deep crust. The surface magnetic data are upward-continued to a 100 km for comparison with MAGSAT satellite magnetic data, downward-continued to a same altitude of 100 km and low pass filtered for wavelengths larger than 500 km. Upward-continued surface data and downward continued MAGSAT data show good morphological similiarity for wavelengths in the range 200-500 km at altitude of 100 km. Satellite data permit the characterization of magnetic signatures due to sources located in the lower crust of Dalmatia, Sardinia and Lombardia, while further surface regional anomalies are connected with upper crust bodies of middle Tyrrhenian sea and southern Sicily.

A NORMAL GEOMAGNETIC REFERENCE FIELD IN THE IONIAN SEA AREA

M. Chiappini, A. De Santis, G. Dominici (Istituto Nazionale di Geofisica, Vigna Murata 605, 00143 Roma Italy)
M. Torta (Observatori de l'Ebre, Roquetes, Tarragona, Spain)

The area of the Ionian sea, between Albania and the Southern Italian Peninsula, has been taken into account for the production of geomagnetic maps. Data from the national Albanian and Italian magnetic repeat station networks have been merged, and normal reference fields in latitude and longitude, have been computed. Data processing, reduction procedures and comparisons with IGRF are presented.

SPATIAL-TEMPORAL MODELLING OF THE GEOMAGNETIC SECULAR VARIATION, USING OBSERVATORY AND REPEAT STATIONS DATA

V.P.Golovkov, I.A.Burdelnaya, S.V.Filippov (Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moscow Reg., Troitsk, 142092, Russia)

European continent is most covered with magnetic observatories and repeat stations. It permits to develop much more precise model of the geomagnetic field changes over this part of the globe. For this aim a technique of regional modelling was applied to both observatory annual means and repeat stations data. Method of the natural orthogonal components was used to expand the annual means from observatories on the 26 yrs time interval in three numerical functions. Obtained temporal functions as well as some analytical functions commonly used in spatial modelling on the limited part of the Earth's surface were used to develop the algorithm and program of spatial-temporal modellings of geomagnetic field changes over Europe.

ON THE ACCURACY OF EUROPEAN MAGNETIC OBSERVATORIES

V.P.Golovkov, T.A.Chernova (Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moscow Reg., Troitsk, 142092, Russia)

European continet is most on the globe covered with magnetic observatories. Comparison of series of their annual means values of different component of geomagnetic field permints to estimate their accuracy. Some methods of mathematical statistic help to make quantitativ this estimation. A new approach to the problem was developed on use the natural orthogonal component expantion of continuos series of observatory data. This technique forms a set of numerical functions-natural orthogonal componets (NOC's) which linear combinations fit secular changes in observatories. According the used algebra obtained NOC's are absolutly orthogonal each others and residuals in each observatory series do not co-vary others. It means that obtained residuals reflects only local fenomena, no matter if they are errors or have some natural or arteficial origin. Residuals of european magnetic observatories on 25 yrs time interval will be presented.

GEOMAGNETIC MONITORING IN THE UKRAINIAN CARPATHIANS

V.Korepanov (Lviv Centre of Institute of Space Research. Naukova str., 5-A, 290601, Lviv, Ukraine)
V.Kuznetsova, V.Maksymchuck (Carpathian Branch of the Inst. of geophysics, Naukova str., 3-B, 290601, Lviv, Ukraine)

Geomagnetic monitoring in the region of Transcarpathian inner through is executed starting from 1982. This area relates to the moderate seismicity region where 2÷10 earthquakes with k≈8-10 occur every year. The peculiarities of this region allow to study separately each seismic event and to make comparison with theoretical model. The monitoring is conducted on the basis of differential measurements methodology with the help of proton magnetometer at 4 regime stations, operating last 7 years. One basic station in this region is also organized since 1996. A three-axial flux-gate magnetometer with high thermal and temporal stability is operating and collecting data in INTERMAGNET standard. Also secular variation components are determined at 3 stations according to IZMIRAN methods. Besides it geomagnetic investigations have been held at 3 regional profiles in the Western Ukraine in 1990-1995. The methodology of future experiments and corresponding equipment is described.

THE HUNGARIAN MAGNETIC NETWORK AND THE PROCESSING OF THE OBTAINED DATA

P.Kovacs - Eotvos Lorand Geophysical Institute, Hungary
A.Kormendi - Eotvos Lorand Geophysical Institute, Hungary
L.Hegymegi - Eotvos Lorand Geophysical Institute, Hungary
M.Chiappini - Instituto Nazionale di Geofisica, Roma, Italy
G.Dominici - Instituto Nazionale di Geofisica, Roma, Italy

A geomagnetic survey was carried out in 1994-1995 in the territory of Hungary and neighboring regions on 195 stations. Magnetic declination, inclination and total field were measured. Some of the stations were measured jointly with ING, Roma. The results were reduced to the epoch 1995.0. Normal field for magnetic D, I, H, F, and Z was determined as a second order function of geographic coordinates. The polynomial coefficients have been computed in two ways: by means of a least squares procedure and using adjustments to the "most frequent value". In the present study the summary of mathematical theory for these two methods and differences between two results are presented.

ESTIMATION OF THE LITHOSPHERE FEATURES OF EARTH AND PLANETS BY MEANS OF AVERAGE GEOPHYSICAL CHARACTERISTICS

V.N.Lugovenko ,A.V.Pchelkin (Institute of Terrestrial Magnetism,Ionosphere and Radio Wave Propagation,Mosßow Reg.,Troitsk,142092, Russia)

We obtained dependences of statistical characteristics of the Earth's magnetic anomaly and gravitational anomaly fields at the survey altitude and carried out the joint correlation analysis of magnetic and gravitational fields and the physical-geological interpretation of a number of territories. Besides the dependences between statistical characteristics of the gravitational anomaly field and lithosphere structure for Earth,Venus, Mars and their satellites Moon and Fobos.It was shown that some geophysical characteristics of planets and their satellites have the connection with the "golden section". Essentially, the Earth's lithosphere as upper covers of other planets of the Earth's group and their satellites present the open dynamic systems, which are exchanged between itself and surroundings, a matter and an energy. Moreover the processes in the planets relate to processes of the weak linear unbalance and as a matter of fact this self-organized unbalance of geological processes, which is the result of synergetic principles and lead to idea of certain general lows in the structure of upper covers of different celestrial bodies.

SECULAR VARIATIONS IN EUROPE IN THE 2nd PART OF THE 20th CENTURY

V.Yu.Maksymchuk (Carpathian Branch of Institute of Geophysics NASU, 3"b" Naukova Str., 290601, Lviv, UKRAINE)

The spatial-temporal structure of secular geomagnetic variations in Europe in 1950-1990 is studied according to magnetic observatory data. Two SV focuses are shown to exist: Arctic with its epicentre in the north of Europe and European with the epicentre in the Southern Europe. Both focuses are characteristic of low intensities (20-40 nT/year). Their travel paths are studied. The European focus is considered to have appeared in the Southern Europe (in the Baulcanic region) in 50-s due to the decaying Caspian (Iranian) focus moved here. The Arctic focus moved to Scandinavia in 70-s. It is drifting south at speed 10-15 deg./year during certain periods. In late 70-s the Arctic focus collapsed but the European focus is still present in the south of Europe. The depth of SV focus sources is calculated. Despite morphology defferences as well as differences in intencity and drift speeds, source depths appear to be close and within 3500-4550 km what corresponds to the Earth's core liquid part.

SECULAR VARIATION REGIONAL ANOMALY OF LITHOSPHEREC ORIGIN IN EUROPE

Maksymchuk Valentyn Yu. (Carpathian Branch of Institute of Geophysics NASU, 3"b" Naukova Str., 290601, Lviv, Ukraine).

In 1957-1995 basing on magnetic observatory data secular variation analysis of magnetic field was carried out to detect its anomalous component associated with processes in the Earth's crust and the upper mantle. Separation of the normal field and determination of SV anomalous component together with its spatial and spectral characteristics are due to the analysis methods developed. SV normal field is described by optimal power polynomial. Positive stational regional anomaly with intensity of 1,5-2,0 nT/year is detected in the structure of SV anomalous field and in the vertical component δZa. The anomaly stretches from England towards the Black Sea. Correlation between δZa, tectonic elements and geophysical fields is observed. The positive zone δZa coincides with Alpian and Hercynic folded structures. The East-European Platform and the Western Europe are characterized by a negative value δZa. The anomaly is attributed to deep geoelectric inhomogeneity in the upper mantle. The source depth is 150 km. It is associated with an inductive influence of external magnetic field variations.

A NEW DIGITAL MAGNETIC ANOMALY COMPILATION IN THE NORTHERN RUSSIA AND ARCTIC SHELF

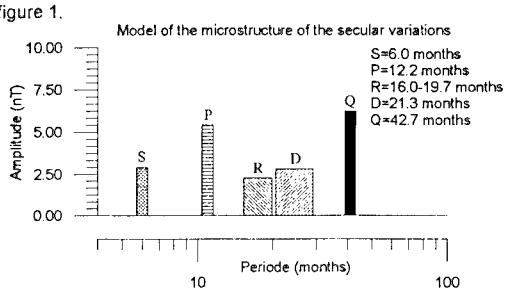
S.P. Maschenkov, V.Yu. Glebovsky, Korago E.A. and A.V. Zayonchek (VNIIOkeangeologia 1, Anglyisky pr., St. Petersburg, 190121, Russia; dsggi@g-ocean.spb.su)

A new digital magnetic anomaly compilation of the onshore and continental shelf areas off northern Russia has been developed with data collected during aero- and marine magnetic surveys carried out in 70-80's. The magnetic profiles were digitized, adjusted, gridded and merged with available digital magnetic anomaly grid compiled by Geological Survey of Canada (Macnab et al., 1996). The merged data sets are presented as a color shaded relief magnetic anomaly map at scale 1:5,000,000 based on the 5x5 km grid that covers the portions of northern Russia and Northern Eurasian shelf. The matching tectonic zonation overlay identifies the imprints of important geological structures in anomalous magnetic field. There are evident differences in magnetic anomalies amplitudes and shapes between the east and west parts of Northern Russia.

STRUCTURE SPECTRUM OF THE GEOMAGNETIC FIELD SECULAR VARIATIONS - EUROPEAN GEOMAGNETIC OBSERVATORIES

S. Mihajlovic, A. Djordjevic, **V. Milicevic**, M. Obradovic (Geomagnetic Observatory Grocka, 11306 Grocka, Yugoslavia)

In this paper, the structure spectrum of the geomagnetic field variations analyze of the geomagnetic field elements, registered on the middle latitude observatories will be presented. On the basses of results that analyze, model spectrum microstructure secular variations of the geomagnetic field elements for the middle latitude observatories, has been done. That is shown on figure 1.



STRUCTURE AND MORPHOLOGY OF REGULAR DAILY S_R GEOMAGNETIC FIELD VARIATIONS ON SECULAR STATIONS IN YUGOSLAVIA

M. Obradovic, S. Mihajlovic, A. Haskic, J. Jankovic (Geomagnetic Institute Grocka, 11306 Grocka, Yugoslavia)

In the 1994, on territory SR Yugoslavia, the geomagnetic field changes measurements, on secular stations, has been done, according standard methods:

- registrations of the geomagnetic field variations for 3-5 days, duration on secular station
- the absolute values measurements of the geomagnetic field elements, near the secular station.

In this paper, the morphology and structure of registered daily variations S_R on secular stations, will be shown. Regular daily variations S_R, registered on secular stations, with regular daily variations, registered on Geomagnetic Observatory Grocka, will be comprised. The regional component in shown spectrum of regular daily variations structure, will be indicated.

On the bases results of regional component S_R analyze, could be discussed about regular daily variation S_R changes, on territory SR Yugoslavia.

MODELLING OF THE MAGNETIC ANOMALY FIELD FOR THE SOUTH-WESTERN PART OF THE EAST-EUROPEAN PLATFORM

M.I.Orlyuk (Institute of Geophysics of the National Academy of Sciences of Ukraine, 32, Palladin ave., 252142 Kyiv, Ukraine)

The region encompasses the following modern tectonic structures: Ukrainian shield, Belorussian and Voronezh massiv separated by the Pripyat-Dniper-Donets and Volhyn - Orsha aulacogens.The nearsurface magnetic field , its longwavelength component and the MAGSAT-anomaly were used for comprehensive interpretation . Petromagnetic data on rocks from the upper crust, the depths to the Pre-Riphean basement, the Mohorovicic discontinuity, and the isothermal surface of 580 ^{0} C (corresponding to the Curie temperature of magnetite) were used as *a priori* information. Within this region there are large areas, of size 300 x 500 km, with 0.5-1.5 A/m magnetization of the solidifid eart's crust. These areas generelly contain sources of longwavelength magnetic anomalies, 40-100 km wide, with 2.0-4.0 A/m magnetization of the lower crust. Hence two large strip of NW bearing can be identified. One of them corresponds to the ensemble of sources of the SW edge of the East-European platform. The second is traced trough the Kursk anomaly. The third line of latitude strike runs parallel to the southern boundary of the platform. Development of 3-D magnetic models for large regions provides for analysis of the earth's reference field for the presence of anomalies associated with the formation of the earth's crust, which cause "false" anomalies in the field (ΔT)a.

DIGITAL MAGNETIC ANOMALY MAP OF CENTRAL,NORTHERN AND EASTERN EUROPE: PROBLEMS OF INITIAL DATA AND REFERENCE FIELD

I.K.Pashkevich (Institute of Geophysics, National Academy of Sciences of Ukraine, Palladin ave., 252142, Kyiv, Ukraine)
W.Bosum, S.Greinwald, T.Wonik, K. Trippler, H. Geipel (Federal Institute for Geosciences and Natural Resources, Stilleweg 2, D-30655 Hannover, Germany)

For compilation of Didital Magnetic Anomaly Map two databases were used: 1) the digitized magnetic anomaly map of the former USSR at a scale 1:2 500 000 by Makarova (1974) and 2) magnetic anomaly map of Central and Northern Europe by Wonik (1992). The first was based on the results of the aeromagnetic surveies with different: altitude, scales, accuracy, directions of the flight lines and were made in various years and with using inhomogeneous secular varition data. As a result map of the former USSR in spite of using strong airborne profiles network and single reference field (1965), contains irregular errors. They are characterized especilly for the near western state bor der areas. The magnetic anomaly map of Central and Northern Europe was compiled for the altitude 3 km and with using DGRF 1980. To combine both these data set following procedures were made: a) the data for former USSR were continued upward to an altitude 3 km; b) the DGRF 1965 was calculated for this territory ; c) the magnetic anomaly map of the former USSR was reduced to the DGRF 1980 with using differences between both references fields and with taking into account the secular variations 1965-1980. Neverthelers, airborne magnetic profiles measurements are necessar foı optimization of the results.

ON THE NEWLY-ESTABLISHED REPEAT STATION NETWORK IN YUGOSLAVIA

D. Popeskov
M. Popeskov (all at: Geomagnetic institute, 11306 Grocka, Yugoslavia)

In this review we give a brief summary of the geomagnetic observations on a newly-established repeat station network. In order to test collected data, we have calculated normal field for the epoch 1990.0 in the form of the first, second and third order polynomials, which are compared with the International Geomagnetic Reference Field (IGRF) for the same epoch.

COMPARASION OF THE IGRF MODELS AND MEASURED MAGNETIC FIELD OF THE EARTH IN SOUTH-EASTERN PART OF EUROPE.

D. Popeskov
T. Bicskei
A. Haskic (all at: Geomagnetic Institute, 11306 Grocka, Yugoslavia)

Results of the contemprorary geomagnetic surveys of countries from mentioned area reduced to the epoch 1980.0 have been used in order to compare with IGRF 1980 and different candidate models IGRF 1985. The normal geomagnetic fields for each element were computed (using a different degree polynomial in latitude and longitude) and comparasions were made with relevant reference fields.

AN INTERPRETATION OF THE MAGNETIC MAGSAT-ANOMALIES IN CENTRAL EUROPE

R. Pucher and T. Wonik (NLfB-GGA, Stilleweg 2, 30655 Hannover, Germany)

The magnetic map, deduced from MAGSAT satellite data (altitude 350 km) by Taylor & Ravat (1995) shows a pair of magnetic anomalies for the area of Poland and Germany: a minimum in the SW and a maximum in the NE. The border between both parts coincides with the NW-SE running Thornquist-Teisseyre Zone, an old suture zone which devides the Palaeozoic platform of Central Europe from the Precambrian shield of Eastern Europe.
The anomaly pattern gives the impression that it is caused by only one magnetized body and not by neighbouring crustal parts of different age, structure, and magnetization direction. There are indications that the magnetization of the Palaeozoic platform is mainly caused by pyrrhotite with predominating remanent magnetization.
The paper presents an ensemble of threedimensional model bodies located within the Palaeozoic platform which can explain both parts (maximum and minimum) of the anomaly pattern.

Regional magnetic charts of Sweden

T. M. Rasmussen and B. Olafsdottir (Geological Survey of Sweden, Box 670, S-751 28 Uppsala, Sweden)

Magnetic field measurements obtained from various surveys in Sweden are presented. The data and their quality are discussed and we describe the possibility of integrating different types of data for the construction of regional magnetic charts. The data consist of three-component ground observations, measurements at sea and total field aeromagnetic data. The number of the ground observation sites is about 10000, evenly distributed and covering most of Sweden. The three-component measurements at sea cover parts of the territorial waters of Sweden. The problems due to secular variations when integrating data obtained during different epochs are discussed. Furthermore, we discuss the problems related to construction of charts from data obtained at different altitudes.

MODEL OF THE MAGSAT ANOMALY MAGNETIC FIELD OVER EUROPE USING SPHERICAL CAP HARMONIC ANALYSIS

N.M.Rotanova,D.S.Odintsov (Institute of Terrestrial Magnetism,Ionosphere and Radio Wave Propagation, Moscow Reg., Troitsk, 142092, Russia,e-mail: odintsov@izmiran.rssi.ru)

Using the gridded values of the MAGSAT anomaly magnetic field over Europe (between latitudes 6N and 60N, longitudes 19W and 70E) and the method of spherical cap harmonic analysis, a spherical cap harmonic model of the magnetic anomaly field has been constructed. The pole of the cap is at lat. 33N, long. 26E, its half-angle is 50. The maximum index (Kmax) of the model is 18, the total of the model coefficients is 361. The maximum spherical harmonic degree corresponding to this index is 41, giving a minimum wavelength at the Earth's surface, of ~1000 km. The RMS deviations between the calculated and initial values are ~4 nT for X, ~3 nT for Y and 3,5 nT for Z respectively. Model of the spherical cap harmonic analysis is used to obtain the satellite magnetic anomaly maps for X,Y,Z at different altitudes (altitudes are 300 km, 400 km, 500 km, respectively). The spherical cap harmonic models with different Kmax values are calculated. The created models can use for the detail investigation of the lithospheric structure over Europe.

NEW METHODS OF APPROACH FOR THE INVESTIGATION OF DEEP STRUCTURE OF MAGNETIC ANOMALY SOURCES

Tsvetkov Yu.P., Rotanova N.M., Pchelkin A.V. (Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moscow Reg., Troitsk, 142092, Russia)

The results of interpretation of magnetic anomaly sources by experimental data from three magnetometers vertically separated along a 4 km line were obtaind. It was shown that a decrement of magnetic anomalies increases as an altitude increment from the Earth's surface. This increase of degree damping depends on the change of source geometry by expansion of influence zone of field sources as the altitude inreases. It was shown, that a measured vertical gradient at stratospheric altitudes presents the sources of all magnetoactive litosphere layer. It forms by bedding depth and geometric dimensions of soursec, placed along the vertical line, that is geomagnetic field parameter, which is resultative for the investigation of deep structure of magnetic anomaly Sources.

Analysis of the geomagnetic anomaly within the Kolárovo basin using GMINV.

Fridrich Valach (Geophysical Institute SAS, 947 01 Hurbanovo, Slovakia).
Magdalena Váczyová (Geophysical Institute SAS, 947 01 Hurbanovo, Slovakia)

GMINV is a computer program for inversion of potential field data using the damped approximate technique. In this paper we evaluate the results of geomagnetic field mapping in the area of Kolárovo basin magnetic anomaly, south-west Slovakia. In order to achieve more precise evaluation of the location and geometry of the perturbative body we use some preliminary knowledge concerning the geological structure of the locality, magnetic profile measurements, etc.

SE26 Comparing electromagnetic studies of the crust and upper mantle: east and west of the Tornquist-Teisseyre zone

Convener: Junge, A.
Co-Conveners: Cerv, V.; Rasmussen, T.M.; Vanyan, L.L.

STRUCTURE OF THE PALEOZOIC GRAPHITIC CONDUCTOR IN W HUNGARY

A. Ádám (Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, H-9401 Sopron, POB 5, Hungary)
G. Varga (L. Eötvös Geophysical Institute, H-1545 Budapest, Columbus u. 17-23, Hungary)

In the sixties a large conductivity anomaly has been discovered in Transdanubia (W-Hungary) by telluric and magnetotelluric soundings. Its structure and relation to the geology and tectonics of the area became more and more clarified by systematic EM induction studies.

The induction vectors (arrows) distinguish two anomaly stripes of 15-20 km width in NE-SW direction in the Bakony Mts and in its NW foreground. The conductors lie at a depth of about 5 and 10 km under Mesozoic limestones supposedly connected to Paleozoic graphitic shales.

The conductors consist of quasi parallel isolated blocks elongated in the direction of the NE-SW longitudinal fractures as concluded from the clear separation of the E and B polarized Rho sounding curves on the basis of the static distortion.

Nevertheless, the role of the transversal fractures cannot be neglegted cutting the longitudinal blocks into 3D elements as shown by long period induction vectors (T > 20 min), pseudosections and 2D inversions recently calculated by GEOTOOLS. 2D inversions hint at the thrusting of the blocks along detachment plane certainly connected to the accumulation of graphite and fluid.

THE INFLUENCE OF A RANDOM CRUSTAL CONDUCTIVITY DISTRIBUTION ON LONG PERIOD ELECTROMAGNETIC SOUNDINGS

K. Bahr (Institut fuer Geophysik, Herzberger Landstr. 180, 37075 Goettingen, Germany)
T. Korja (Geophysics, Villavaegen 16, 75236 Uppsala, Sweden)

Recent mid-band and long period electromagnetic soundings in Central Finland suggest that the crust is strongly heterogeneous with respect to conductivity. Scandinavia provides a few regions with very small crustal conductance which can serve as a 'window to the mantle' in long period studies. But crustal conductors as far as 100 km from a particular long period site can significantly distort the long period transfer functions. In order to check in as much lack of knowledge about the crustal conductance between widely spaced long period sites can result in a spacial alias problem, a random model study has been performed. The crustal conductor was simulated using Weidelt's algorithm, and the crustal conductance distribution within a 200 * 200 km environment of the long period site was varied randomly. The results allow us to develop a strategy by which during the actual field procedures of the SVEKALAPKO project a dense mapping of the crustal conductors can be avoided.

GEOELECTRICAL MODELLING OF THE WESTERN PART OF THE BOHEMIAN MASSIF

V. Červ, J. Pek, O. Praus (Geophysical Institute, Acad. Sci. Czech Rep., Boční II/1401, CZ-14131 Prague 4, Czech Republic)
B. Pícha, E. Hudečková (Geofyzika Inc. Brno, Ječná 29a, CZ-61246 Brno 12, Czech Republic)

A series of geoelectrical soundings, carried out in West Bohemia in recent years in connection with the German deep drilling experiment KTB, has been interpreted in terms of the profile versus depth cross-sections of the spatial distribution of the electrical conductivity in the earth's crust of the western part of the Bohemian Massif. The experimental inputs consisted of broadband AMT and MT data along the seismic reflection geotraverse 9HR in West Bohemia, long-period induction data from the profile Cheb-Tachov-Nýrsko, located immediately along the Czech-German border, and results of geoelectrical experiments from the immediate vicinity of the KTB drilling site in Germany. The interpretation proved a geoelectrical structural similarity between the KTB area and the westernmost region of the Czech territory. A significant change takes place approximately along the West Bohemian fault zone, with significantly increased conductivity systematically indicated in the crust of the Teplá-Barrandien Proterozoic unit. The geoelectrical section along the geotraverse 9HR conforms in principle with the complex geological model of the region. A pronounced conductivity anomaly is indicated at the contact zone between the Teplá-Barrandien zone and the South Bohemia Moldanubicum.

ELECTROMAGNETIC SOUNDING AROUND THE TATRA MOUNTAINS

T. Ernst, J. Jankowski, V.J. Semenov and W. Jozwiak (Institute of Geophysics, Ks. Janusza 64, 01-452 Warszawa, Poland)
A. Ádám, L. Szarka and V. Wesztergom (Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, H-9401 Sopron, POB 5, Hungary)
M. Hvozdara (Institute of Physics, Dubravská 9, 842 28 Bratislava, Slovak Republic)

Seven deep electromagnetic soundings were carried out at a 150 km N-S profile crossing the High Tatra mountains. Five electromagnetic components have been recorded simultaneously during 3 weeks in the period range of 10-10000 s. The real induction vectors were estimated at all sites and data from 3 stations were used for magnetotelluric sounding. The 2-D modelling identified the location of the Carpathian conductivity anomaly just beneath the High Tatra at a depth of 10-20 km. This anomaly could be explained by presence of porewater in deeply burden sediments. The 2-D modelling has confirmed shallower conductive asthenosphere at the southern end of the profile in the Pannonian Basin.

MAGNETOTELLURIC STUDY OF THE CALEDONIDES IN JAMTLAND, SWEDEN

M. Gharibi, T. Korja and L.B. Pedersen (University of Uppsala, Sweden)

The central part of the Scandinavian Caledonides consists of several nappes over thrust from W or NW over the Proterozoic basement. The thrust decollement is composed of a sequence of autochthonous or para-autochthonous sedimentary rocks including also layers of carbon-bearing black shales (alum shales). Fifty natural (8000 Hz ~ 3000 s) and fourteen controlled source (8000 Hz ~ 1 s) magnetotelluric soundings were carried out along a 170 km long section of the reflection seismic profile. The magnetotelluric profile starts 35 km east of the Caledonian Front and terminates at the Swedish-Norwegian border allowing us to study the electrical properties of the Caledonian rocks and the Proterozoic basement as well as the basement-cover relationship. Most of the sites indicate a two dimensional structure with a regional strike of nearly N-S direction. The estimated strike coincides well with the dominant orientation of the geological structures in the Jamtland area. The 2-D inversion of the magnetotelluric data show that the uppermost part of the crust has resistivities of a few hundreds of ohm metres. Beneath that a highly conducting layer is imaged. The layer dips gently to the west (ca. 1 degree) with the resistivity varying from 10 to below 0.1 ohm metres. The resistivity is increasing towards the east where the alum shales are closer to the surface. The conductive caledonian rocks and the decollement are underlain by a more resistive material plausible representing the (reactivated?) Precambrian basement.

DEEP ELECTROMAGNETIC SOUNDINGS ACROSS THE TT ZONE IN THE UKRAINIAN CARPATHIANS

N.G. Golubev, Iv.M. Varentsov (Geoelectromagnetic Research Institute RAS, 142092, P.O.B. 30, Troitsk, Moscow Region, Russia);
V.V. Gordienko, S.N. Kulik, I.M. Logvinov (Institute of Geophysics NAN, prosp. Palladina 32, Kiev - 180, Ukraine);
V.I. Tregubenko (KGO UkrGGRI, ul. Avtozavodskaia 78, Kiev - 114, Ukraine)

The first detailed deep electromagnetic study of the Ukrainian Carpathians based mainly on generalized 2D inversion of geomagnetic responses along the KAPG geotraverse II and supported by geothermal models (Zhdanov et al., 1986, 1993) had shown very complicated geoelectric structure in this section of the TT zone, namely the valuable sedimentary structure in the Precarpathian trough, the sharp crustal conductivity anomaly in Transcarpathian area and the well developed asthenosphere traced from Pannonia to the Carpathian arc (with upper edge at the depth of 70-80 km) and absent at the platform.

Since that time about 20 MT soundings with period range of 10-4000 s were done in this area by KGO UkrGGRI, new tools for sophisticated simultaneous inversion of GDS and MT data appeared (Golubev, Varentsov, 1988-1996; Varentsov et al., 1996), and heat flow measurements and geothermal models were revised (Gordienko et al , 1996). In this paper we start the re-interpretation of available EM data using new techniques and all the background of geologo-geophysical studies along this geotraverse. The main targets include anomalies mentioned above, and the studies of the regional deep normal section and of the upper crustal fine structure between the Precarpathian and Transcarpathian troughs are considered.

THE I.M-SOUNDING IN DNEPROVSK DONETZ DEPRESSION(DDD)

A.I.Ingerov Slavuta Co Ltd. Dniepropetrovsk Ukraine
I.I.Rokityansky Institute of Geophysics, Kiev Ukraine
Y.T. Vlasov Slavuta Co Ltd . Dniepropetrovsk Ukraine

700 deep MTS and 50 GDS were carried out in DDD. Besides there is about 1500 MTS in 0.1(10)-600s and more than 10000 CSAMT for oil and gas prospecting. A map of total lougitudinal conductivity of the sediments(S) was obtained using these data in the scale 1:1000000. The depression is divided clearly into 2 different parts (west and east) on the level of(S). There is the narrow connection between S and thickness of the sediments in the west part, where conductivity of the sediments on axes of DDD is more than 2000Sm. The regional alterations of the average longitudinal resistance permits in this party to separate the provinces with good collector properties of the productive for oil and gas rock mass. Inspite of the high conductivity and thickness of the sediments on the territory with length on the latitude about 140km the powerful conuctor is observed in the deep crust on the depth 20-30km. stretched in the meridional direction. The conductivity of the sediments in the east party DDD decreases abruptly to 100-300Sm caused high degree of rock metamorphism. South Donbass anomaly of electroconductivity discovered in 1985 comes forward on this background. The anomaly is stretched in the latitudinal direction. There are anomalies of the thermal flow, the gravitation anomalies and anomalous structure of crust was determined on data of the deep refraction seismics. The new results EM-modelling of EM anomally are discussed.

PRELIMINARY RESULTS MTS IN SOUTH-WEST UKRAINE

A.I.Ingerov Slavuta Co Ltd. Karl Marx Ave 33, Dniepropetrovsk 320044 Ukraine
I.I.Rokityansky Institute of Geophysics, Kiev Ukraine
Y.T. Vlasov Slavuta Co Ltd . Karl Marx Ave 33, Dniepropetrovsk 320044 Ukraine

Tornquist - Teisseyre zone crosses the territory of South-West Ukraine where about 1000 MTS and 100 GDS have been made last 2 decades. Common feature of both amplitude and phase MTS cerves is presence of expressive extrema and bendings that correlate in adjacent points and carry infromation about conducting layers in sediments, deeper crust and upper mantle. In many points extrema are more contrast that can be derived from 1-D models. Generalized geoelectrical model of Ukraine contains two crustal conductions layers: first one is at the depth 5-15 km with conductivity 100-1000 Sm, second one at 15-30 km with conductivity 400-3000 Sm. Map of the layers is given. In the East-European platform crust conductivity is anisotropic in some place where meridional total conductivity exceeds the latitudinal one. Comparison with deology, geophysical data and foult tectonics is also discussed.

ELECTROMAGNETIC SOUNDINGS NEAR TT ZONE IN POLAND

J.Jankowski, **V.Semenov**, T.Ernst, W.Jóźwiak (Institute of Geophysics Ks. Janusza 64, 01-452 Warszawa, Poland)

Ten deep electromagnetic soundings were carried out at the 150 km long profile situated perpendicular to the southern part of the TT zone in central Poland. Five electromagnetic components have been recorded in the period range from seconds to several hours. The real induction vectors were estimated at all sites and data from six stations were used for magnetolluric soundings. The 2-D modelling has shown the existence of a deep conductive fault at the northen part of the Holy Cross Mountains (HCM), left hand and right hand sides from which are characterised by the different geolectrical structures. According to the correlation between this and older MT measurements at that area the detected structure has prolongation to the east from the HCM. Taking into consideration the influence of the Carpathian magnetic anomaly it was suggested that just beneath the TT zone there exists a conductive layer at a depths near to the crust end. As the base points for the deep structure modelling, the data from Belsk and Hel geomagnetic observatories were considered.

2D INVERSION OF ELECTROMAGNETIC DATA IN SE SCOTLAND

A. Junge (Frankfurt University, Feldbergstr. 47, 60323, Frankfurt/Main, Germany);
Iv.M. Varentsov (Geoelectromagnetic Research Institute RAS,
142092, P.O.B. 30, Troitsk, Moscow Region, Russia)

The dominating geological crustal feature in SE-Scotland is the Iapetus Suture Zone. Thus it has been the target of many EM field investigations among the most recent were those of Banks et al., 1996, which covered the long period range up to 10000 sec and ends south of Edinburgh. A high conductive 2D midcrustal body was detected at the Northern end of the profile. It's strike direction corresponds to the dominating NE-geological strike and might be associated to the Suture Zone. However the shape of this body could not be resolved accurately and thus a rather dense profile across the Midland Valley further to the North was established. It consisted of 12 MT sites out of which 3 sites were recording simultaneously at a time. Thus high quality transfer functions between horizontal magnetic fields at different sites as well as the traditional MT and GDS transfer functions could be estimated in the period range between 100 - 100000 sec.
As the transfer tensor decomposition allowed a 2-D assumption for the midcrustal conductivity anomaly, a 2D inversion of the data was performed by the interactive robust algorithm of Golubev and Varentsov, using the broad ensemble of available transfer functions. In the presence of considerable static shift in apparent resistivities the greatest priority in the inversion was given to impedance phases and magnetic responses. The inversion yielded a high conductive body of about 2000 S conductance in the volume of about 50 km width and 60 km depth striking NE with its Northern edge being in the Firth of Forth. There is obviously no correspondence of this object with the surface geology. Also the conducting zone at the asthenosphere level is preliminary outlined, but still needs better resolution.

MODELLING OF GEOMAGNETIC TRANSFER FUNCTIONS ON THE EASTERN MARGIN OF THE BOHEMIAN MASSIF

S. Kováčiková, V. Červ, O. Praus (Geophysical Institute, Acad. Sci. Czech Rep., Boční II/1401, CZ-14131 Prague 4, Czech Republic)

In the last 25 years a large set of more than 150 long-period (periods from 700 to 7000 s) geomagnetic transfer functions has been collected in the contact zone between the Bohemian Massif and the West Carpathians and above the eastern margin of the Bohemian Massif. Morphological studies of the spatial distribution of the transfer functions indicate two induction anomalies in the region—the Carpathian conductivity anomaly and another anomaly at the western margin of the Brunovistulicum. While the Carpathian anomaly displays a quasi-2D character, the other anomaly is evidently affected by a 3D conductivity distribution. To explain the principal features of the conductivity distribution within the region, which can generate the surface induction pattern observed, a series of numerical procedures has been applied to the experimental data, involving the hypothetical event analysis, analysis of the equivalent current systems in a thin sheet, bimodal thin sheet modelling, and inversion of the induction arrows for the integrated conductivity in the unimodal induction approximation. The results are discussed with regard to the large-scale tectonic features of the region.

TIME EVOLUTION OF THE MAGNETIC AND MAGNETOTELLURIC TRANSFER FUNCTIONS IN CENTRAL ITALY: POSSIBLE CORRELATIONS WITH SEISMIC ACTIVITY

D. Di Mauro, A. Meloni, P. Palangio (Istituto nazionale di geofisica, via di Vigna Murata, 605 Rome - Italy)
T. Ernst, R. Teisseyre (Institute of Geophysics, Warszawa, Poland)

Since Summer 1991 a magnetotelluric recording station is operating at Collemeluccio (41 43N, 14 22E) in Central Italy. As part of a joint reserch project between the Warsaw Academy of Science (Poland) and the National Institute of Geophisycs (Italy), stability and instability of the magnetotelluric parameters and their possible relations to seismic activity, seasonal phenomena and solar activity are presented. The frequency domain analysis of the inducing field, simultaneously recorded at L'Aquila Observatory, widened the knowledge of the geophysical setting carried out in this area by a previous magnetovariational survey.

PHYSICAL PROPERTIES OF MATTER OF THE UPPER MANTLE OF THE MARGINAL BASINES OF THE PACIFIC: INTERPRETATION OF THE GEOELECTRICAL DATA

A.M.Kutsov, A.M.Lyapishev
Institute of Marine Geology & Geophysics, Yuzhno-Sakhalinsk 693002
Russia.

By the marine electromagnetic sounding technique on different morphostructure elements of different aquazones (ocean, inner and outer seas) wos obtained new data of deep electric conductivity. The important application of the deep geoelectric techniques is detecting of high electric conductivity zone and measuring their geothermal and physical parameters, creating high conductivity, such as mineralisation and partial melting. The values of thouse parameters are important for understanding of the deep processes, and of the geothermal and geodynamic state of the earth interior. A combined interpretation of the original electric and published petrology data is carried out to impose constraints on the state of melting below marginal basines of the Pacific. The theoretical conductivity models are based on published laboratory data on conductivity of solid and melt phases of rocks. A large amount of partial melt (≥5 vol.%) and temperature 1300-1400°C are inferred in the partial melt zone under the Okhotsk Sea. A velocity drop is about 6-10%. A melt fractions under the Western Caroline basin are 8-9 vol.%, under the Eauripik and under the Ontong Java plateau - 1 and 3 vol.%.

THE EXPERIMENTAL RESULTS OF THE DEEP ELECTRIC CONDUCTIVITY IN THE NORTWESTERN ULLEUNG BASIN, EAST SEA OF KOREA

A.M.Lyapishev*, B.-C.Suk**
* Institute of Marine Geology & Geophysics. Yuzhno-Sakhalinsk 693002
Russia.
** Marine Geology & Geophysics Division. KORDI, Ansan P. Box 29. Seoul
425-600, Korea.

Theoretical fundamentals, processing and field setup are presented for applications of the vertical gradient of the total geomagnetic field vector which is registrated by vertical (as depths vary) spacing magneto-variation modules to obtain the electrical conductance structure of the Earth's crust and upper mantle, the magneto-variation gradient soundings (MVGS) were carried out at two points over the Ulleung Basin of the East Sea (Sea of Japan): MVGS-1 (37°20.2'N, 130°47.1'E) and MVGS-2 (37°00.2'N, 130°03.3'E). The geoelectrical structures of the electrical conductances on these points are similarly shown in lower part of the Earth's crust where the high conductance layers appear at 25-30 km depth. Whereas the high conductance layer was identified at a level of 9-11 km only on station MVGS-2. The obtained data well coincide here with high values of the heat flow field and the seismic velocity distributions.

THE EFFECT OF SPATIAL NON UNIFORMITY OF ARTIFICIAL ELECTROMAGNETIC SOURCE ON MAGNETOTELLURIC IMPEDANCE TENSOR.

P.Palangio(Istituto Naz.Geofisica, Castello Cinquecentesco, 67100 L'Aquila Italy)
G.Santarato(Istituto di Mineralogia,Universita' di Ferrara, via Ercole d'Este 3, Ferrara, Italy)
A.Meloni (Istituto Naz.Geofisica,via di vigna Murata 605, 00164 Roma)

Magnetotelluric measurements were undertaken in the Central Italy, about 20 Km from Sangritana railway (Abruzzo region) D.C. powered. Results of a study to investigate the effect of a spatial inhomogeinity of artificial source field on magnetotelluric impedance tensor and tipper are presented. Results are shown when the railway was working and natural magnetic activity was low on average (K-index < 3). Investigation was undertaken above and below the crossover frequency range of railway electromagnetic signal (near and far field).Results show the correlation between railway e.m. signal and magnetotelluric tensor elements and tipper.

ELECTRICAL CONDUCTIVITY IN BLACK SHALES UNDER SIMULATED CONDITIONS BENEATH ORIGINAL BURIAL DEPTH

Siegfried Raab (GeoForschungsZentrum Potsdam, Germany)

Black shale layers may be one possible explanation of good conducting zones in sedimentary basins. In most cases direct evidence is unavailable because these structures are in almost all cases inaccessible by boreholes. The usual approach is to conduct laboratory investigations of rock samples collected at the Earth`s surface or, occasionally, from boreholes. But due to cooling and pressure release they may lose their insitu connectivity. This means that it is neccessary to investigate the rock samples under high temperature and pressure conditions to get insitu data. Because of technical problems the data base is rather limited.
Electrical conductivity measurements on two black shale samples of different diagenetic/ metamorphic grade were made at a constant pressure of 250 MPa and a temperature range of 20°C to 400°C. The sample of higher metamorphic grade from the borehole "Münsterland 1" (Subvariscian foldbelt, Northern Ruhr district, lower Carboniferous) has already been measured at atmospheric pressure by Duba et al., 1988. They report an increase in resistivity of three orders of magnitude at 400°C. A sample from the same interval was investigated in this study under controlled oxygen fugacity and the same temperature range at 250 MPa. A decrease in resistivity of two orders of magnitude was observed at 320°C down to 0,6 Ω m. The other sample, of much lower diagenetic/ metamorphic grade, was from a deep gas-borehole (North German Basin, Altmark district, Permian). The resistivity of this sample was very high (10^5 Ω m) and the decrease in resistivity with increasing temperature was one order of magnitude.

EARTH'S CRUST ELECTROCONDUCTIVITY OF THE UKRAINIAN CARPATHIANS AND ITS CONNECTION WITH OTHER PARAMETERS

Ya.S.Sapuzhak, O.I.Romanjuk (Carpathian Branch of Subbotin Institute of Geophysics NASU, 3b Naukova Str., Lviv, 290601, Ukraine)

The Carpathian region of Ukraine usually thought of as Pre-Carpathian and Trans-Carpathian Troughs separated by mountain structure of Folded Carpathians and adjoining to it an edge of the East-European Platform are characterized by complex geotectonic structure. Within this region there is a great majority of geotectonic elements, in particular, a boundary between East- and West-European Platforms, Tornquist-Teisseyre line, a series of regional faults etc. The region also favours connections between different physical rock parameters as it has been studied actively as oil- and gas-bearing region by electromagnetic and other geophysical methods. Maps both of total conductivity and average longitudinal resistivity of the region sedimentary cover as well as the Earth's crust geoelectric sections along two profilies of deep seismic soundings are due to these investigation results. Direct linear connections between specific electric resistivity, elastic wave propagation velosity, density and warm conductivity for separate stratigraphic rock systems and a sedimentary cover on the whole are also determined. Results and dependances obtained are useful both for detailed investigating geoelectric peculiarities and for comlex interpretation of the Carpathian region.

EM EVIDENCE FOR FLUIDS IN THE CRUST AND UPPER MANTLE EAST AND WEST OF THE TTZ

L.L.Vanyan (Shirshov Institute of Oceanology, Moscow 117218, Russia)

Astenosphere with conductance about 5000 S, conductivity 0.03-0.05 S/m was revealed in Western Carpathians, Pannonia and Bulgaria. Conductivity level suggests partial melting. It is a result of Cenozoic tectonic activization due to collision of the African and European plates. Contrary, East European plate NE of TTZ had no activization. Consequently there are no regions with the astenosphere conductance of some thousands S. Cooling during the last 1.5-2.5 billion of years provides the retrograde metamorphism of crustal rocks. Water is chemically bound by minerals and does not increase electrical conductivity. Thin sediment cover at shields of East European Platform provides a weak screening of AMT. Therefore resistivity about 30000 Ohmm at upper 10 km was revealed at the Baltic Shield and Byelorussian anticline. Perhaps that resistive brittle layer contains a small amount of meteoric water (through porosity less than 0.1*). Upper 10 kms are underlayed by the layer with small conductance 5-50 S. Conductivity increase is correlating with the depth where the difference of lithostatic pressure and horizontal strain reaches the rock strength that provides cataclastic microcracks development. At deeper horizons water is probably chemically bound. Opposite (prograde) metamorphism should exist in areas of Cenozoic activization. Temperature increase results in water release at depth of middle crust. Free water leads to the crustal conductance increase up to a few hundreds S at France, Germane, Hungary, Bulgaria etc. Nature of the similar increase observed at Central Finland is not clear yet.

MAGNETOTELLURIC STUDIES OF THE CRUST AND UPPER MANTLE ACROSS THE SORGENFREI-TORNQUIST ZONE

T. M. Rasmussen (Geological Survey of Sweden, Box 670, S-751 28 Uppsala, Sweden)
B. H. Jacobsen, N. Balling (Department of Earth Sciences, University of Aarhus, Finlandgade 8, Dk-8200 Aarhus N, Denmark)
L.B. Pedersen (Department of Geophysics, University of Uppsala, Villav. 16, S-752 36 Uppsala, Sweden)

The electrical conductivity distribution within the crust and upper mantle in Denmark and in the southern part of Sweden is discussed in relation to the tectonic evolution of the Danish Basin. Estimates of the electrical conductivity are available from interpretations of magnetotellucic soundings and from drill hole logging. Models obtained from two-dimensional inversions of magnetotelluric data along several profiles are presented and compared with information from drill holes. A three-dimensional model and corresponding magnetotelluric response functions are presented. The tree-dimensional model has been constructed using constraints from seismics and from drill holes. The three-dimensional response functions are discussed and compared with the measured response functions. Furthermore, the tree-dimensional model responses are used in an evaluation of the results obtained from the two-dimensional inversions of the measured response functions.

THE LITHOSPHERIC PARTICULARITIES ON THE BOTH SIDES OF THE TORNQUIST-TEISSEYRE ZONE.

D. Stănică (the Geological Institute of Romania)

A number of 5 magnetotelluric profiles crossing the Eastern Carpathians system were analysed attentively in order to decipher the main features of the lithosphere, related to the existence of the TTZ. Undoubtedly, there are a few characteristics concerning the thickness of the crust, the deep distribution of the resistivity values and the particularities of the sedimentary cover, as well, which reveal the south-western border of the East European Platform.The MT data emphasize the particular structural features differing to East and West about this very important tectonic element which is pointed out from North, to South, along the Eastern Carpathians, as a complex fault-block, being about 10 km broad. It displays the most probably intracrustal suture between the Precambrian and Epipaleozoic platforms. The both platform crusts reveal, at the bottom part, important decreases in resistivity (5-10 ohm.m), as result of the presence of the fluid interconection in the transition from lithostatic to hydrostatic pore pressures .

SE27 Tectonic evolution and thermal structure at mid-ocean ridges

Convener: Blackman, D.K.
Co-Conveners: Hooft, E.; Minshull, T.A.

MAGNETIC SEGMENTATION AT SLOW-SPREADING RIDGE SEGMENTS

Simon Allerton, Department of Geology and Geophysics, University of Edinburgh, Edinburgh, EH9 3JW
R.C. Searle and S. Russell Department of Geological Sciences, University of Durham, DH1 3LE

Inversion of surface magnetic field measurements over slow-spreading ridge segments has identified anomalously high apparent magnetizations at the ends of spreading segments compared to their centres. This effect may be due to either along axis changes in magnetic properties,or in thickness of the extrusive layer.This magnetic segmentation is particularly well developed on the Mid Atlantic Ridge between 28 50'N and 29 15'N, where a two-fold increase in apparent magnetization is observed at the segment end, relative to the centre. A deep-towed magnetometer survey has demonstratedthat, in addition, this inverted magnetization is symmetric at the axis at the centre of the segment, and asymmetric at the ends, with a sharp gradient in magnetization adjacent to the large normal faults of the western valley wall. The magnetic properties of basalts dredged from the valley floor do not exhibit any significant change along axis, suggesting that this is unlikely to be the cause of magnetic segmentation. Infill of a flexural half-graben associated with the large faults by extrusive rocks may provide a mechanism for producing anomalously high and asymmetric apparent magnetizations at segment ends, where the effect of asymmetric faulting is greatest.

HYDROTHERMAL CIRCULATION WITHIN AN HETEROGENEOUS ANISOTROPIC DOMAIN : 2D NUMERICAL SIMULATIONS.

Aron Christine[(1)], Pezard Philippe[(1)] and Angot Philippe[(2)].
[(1)] Laboratoire de Pétrologie Magmatique, CEREGE, Aix-en-Provence, France.
[(2)] IRPHE, Universités d'Aix-Marseille I & II, France.

Most of the time, hydrothermal circulation has been studied numerically within homogeneous rectangular domains with isothermal or adiabatic boundary conditions. In this study, we propose to represent the upper part of the oceanic crust (extrusive layers) as an heterogeneous anisotropic triangular domain, perpendicular to and tilted of few degrees towards the ridge axis. Superposition of massive flows layers and pillow lavas ones compose this domain. Moreover, the episodicity of accretion processes is considered using time-dependent boundary conditions. Here, an analytical model is proposed in order to compute, versus eruption and latency time, the axial heat flux producted by a dyke multiple. These analytical results are used in numerical simulations as variable boundary conditions with time.

Mineralogical and petrological studies indicate that the upper part of the oceanic crust has been altered at low temperatures (<100°C). Comparison between these temperatures and numerical results implies that the axial heat flux should be on the order of 300 $mW.m^{-2}$ which corresponds to the flux producted by a dyke multiple after about 25 years of latency. Moreover, temperatures (then alteration) obtained in the lower part of the heterogeneous domain change significantly with permeability of the upper part, but the reverse is not true.

STUDY OF OCEANIC CRUSTAL STRUCTURE BY SEMI-AUTOMATED INVERSION OF MARINE MAGNETIC ANOMALY DATA: ANALYTIC SIGNAL AND EULER DECONVOLUTION

Robert T. Bird, Mark Pilkington and Walter R. Roest
(Geological Survey of Canada, 1 Observatory Crescent, Ottawa, Ontario, K1A 0Y3 Canada; email: bird@agg.NRCan.gc.ca)

Potential field data can be inverted in two or three dimensions using semi-automated inverse techniques to retrieve source body positions and depths. These methods are used to interpret crustal basement structure in continental settings, and we extend their application to the marine realm. In particular, we apply analytic signal and Euler deconvolution techniques to profiles (2-D) and grids (3-D) of marine magnetic anomaly data, and we compare our results. To constrain input parameters [e.g., structural index (N) for Euler method] for real data, we independently model the ocean crust with known source depths, layer thicknesses, magnetizations and resultant magnetic anomalies. We systematically vary the input parameters (e.g., N) and invert the synthetic anomalies to solve for source positions and depths. Inversions of real data show that magnetic reversal boundaries are clearly located regardless of anomaly skewness. Solutions not related to reversal boundaries may identify more-complex volcanic or tectonic structure which produce magnetic anomalies. We show that in some areas where sparse data inhibit a 3-D inversion, trend reinforcement of the anomaly data prior to the 3-D analysis is useful.

MORPHOLOGY AND FAULTING AT THE MID-ATLANTIC RIDGE AND THE ATLANTIS TRANSFORM FAULT

D.K. Blackman and **D.K. Blackman** (Scripps Institute of Oceanography La Jolla, CA USA)
J.R. Cann, B. Janssen (University of Leeds Leeds, UK)

New bathymetry and sidescan data are used to interpret the tectonic processes occurring at the Mid-Atlantic Ridge near its intersection with the Atlantis transform fault. During a cruise aboard RRS Charles Darwin in May, 1996, we obtained 100and west ridge-transform intersections (RTI) along with several lines of TOBI deep-towed reflectivity data. One of the most interesting features is a planer, corrugated and striated slip surface at the eastern RTI which has a very low dip. The asymmetry of this structure, with respect to the ridge axis, and the overall pattern of fault orientations on the seafloor will be shown for the study area. The observed pattern will be discussed in terms of the interplay between extensional forces, motion on the transform and the rapid changes in thickness of the lithospheric plate in this region.

MORPHOSTRUCTURAL ANALYSIS OF THE WESTERN INTERSECTION OF THE MID ATLANTIC RIDGE WITH THE ROMANCHE TRANSFORM (EQUATORIAL ATLANTIC)

E. Bonatti (IGM-CNR and Lamont Doherty Earth Observatory, Palisades, N.Y., USA)
L. Gasperini, M. Ligi, G. Carrara, F. Chierici, P. Fabretti and S. Susini (IGM-CNR, Via Gobetti 101, Bologna, Italy)
P. Tartarotti, D. Brunelli and A. Cipriani (Dip. di Geologia, Univ. di Padova, Italy)
D. Gilod, A.A. Peyve, S. Skolotnev and N. Turko (Geology Institute, Russian Academy of Sciences, Moscow, Russia)

The Romanche Transform, that offset the Mid Atlantic Ridge (MAR) by over 900km, is part of a large E-W megashear zone that crosses the entire equatorialAtlanticfrom the Ivory Coast/Ghana to the north Brazilian transform margins. We carriedouta high resolution multibeam morphostructural survey and gravimetric of theentirewestern half of the transform, including the western Ridge/Transformintersection(RTI). A set of at least three major valleys branch out eastward from thewestern RTIregion; each valley's orientation differs by roughly 5 to 15 degrees from theorientation of the other valleys. Of these valleys only one is highly seismic,andmarks probably the present day transform boundary; the other two valleys areprobably fossil traces of former transform boundaries, suggesting major changesinthe ridge/transform geometry in this region. The residual mantle Bougueranomaly,obtained by three dimensional gravity modeling including the effects of platethickening on 3D passive mantle flow, the inferred crustal thickness and thetopographic signature suggest an unusually cold mantle thermal regime in thisregion. This suggestion is supported by the absence of the predicted topographic "transform edge effect" at both the eastern and western RTI's.

NEOTECTONICS IN AN ICELANDIC LAKE - THINGVALLAVATN

J. M. Bull[1], J. K. Dix[1], T. A. Minshull[2], N. C. Mitchell[3], K. Thors[4], A. I. Best[1].
[1]Southampton Oceanography Centre, University of Southampton, SO14 3ZH, UK
[2]Bullard Laboratories, University of Cambridge, CB3 0EZ, UK.
[3]Geological Sciences, University of Durham, Durham DH1 4EW, UK.
[4]Jardfraedistofa, Borgartun 18, 105 Reykjavik, Iceland.

Thingvallavatn, a lake in the western branch of the axial rift zone in Iceland provides an ideal natural laboratory in which to investigate the interaction between volcanism, sedimentation and faulting, as the volcanic basement is covered by up to 30 m of laminated sediments which record fault evolution. High-resolution seismic reflection imaging of reflectors within the sediment package potentially enables constraints to be placed on relative timing of faulting.
We spent two weeks in July and August 1996 surveying the lake using high-resolution geophysical tools. Preliminary analysis of the Chirp profiler data together with the sidescan data reveals faults within the sediments and complex relationships between faults and lava flows. The sidescan shows in plan view how displacement is transferred between en echelon fault segments, while the Chirp data show how fault displacement varies along individual fault segments. The Chirp data show characteristic high amplitude events that are interpreted as being single or multiple tephra layers that can be correlated over the lake. Key sites for sediment core retrieval have been identified, the physical data from which will be used to confirm this interpretation and hence further constrain the stratigraphy.

GEOPHYSICAL ASYMMETRY OF THE WINGS OF MID-ATLANTIC RIDGE (MAR): GRAVITY, MAGNETIC FIELDS, HEAT FLOW

Vladimir G. Budanov, Boris V. Yermakov (VNIIGeofizika, Moscow)
Leonid V. Podgornykh (VNIIOkeangeologija, St.Petersburg)

Analysis of thin structure of Δg and assessment of oceanic crust density (σ) was performed for more than 20 profiles crossing MAR from 74°N to 13°S. The general conclusion was made about the density asymmetry of the crust: eastern slope - 2.7 g/ccm, western slope - 2.4 g/ccm (V.G.Budanov et al., 1977, 1980, 1988,1995). The disruption of bilateral symmetry of ΔT at 23° -28°N zone was observed (A.M.Gorodnitsky, 1994, 1995). It was shown that the mean value of heat flow within the Western wing is higher than that within the Eastern wing (60-64 mWt/sq.m and 40-42 mWt/sq.m, respectively). The highest density asymmetry of the crust was observed for the 9°-13°S zone: 2.3 g/ccm and 2.9 g/ccm, respectively. The data on σ of the crust compatible with our results were obtained independently using seismic techniques (V.I.Starostenko, 1994). Seismic data also indicate the presence of a thick (45 km, similar to continental), laterally differentiated crust at the Western wing and a thinner (less than 20 km), dense crust at the Eastern wing. The results indicate a complex and, probably, rather prolonged (judging by the thickness of the crust) process of the crust formation. Thus, the spreading model can hardly be used to make the conclusions concerning the mechanism of the crust formation.

POTENTIAL FIELDS AND DEEP STRUCTURE OF THE VERNADSKY AND VEMA FAULT ZONES, TROPICAL ATLANTIC OCEAN.

Vladimir G. Budanov (VNIIGeofizika, Moscow)

A new version of dG maps was prepared for the vast area about 300 000 sq km. Examination of ΔGb map and seismic (DSP-reflection) data suggest the presence of a mantle depression within the area to the south of the Vema Trench. The mantle depression is oriented in the same direction as Mid-Atlantic Ridge (103°-105°S) but at an angle to major ridges and depressions that are oriented E-W. Vertical movements of the several blocks are confirmed by the geological data. A number of the core samples indicated the changes in sedimentation environment (from deep water to shallow water). This allows for the conclusion that recently (about 130 - 150 thousands years ago) certain areas of the sea bottom at the periphery of 7° 8°N zone were elevated as high as 500 - 1000 m. Intensive, oppositely directed vertical movements were accompanied by the eruption of basalt lavas. As a result, a thick layer (about 30 - 35 km) of relatively low-density (2.2 - 2.4 g/ccm), probably volcanogenic-sedimentary material was covered by a thin layer of fresh basalt in 7°-9°N zone. Rifting occured at the final stage of the formation of the Equatorial Ridge. However not all of the numerous transverse faults could be regarded as transform faults. While the Vema Trench is probably a transform fault, the Vernadsky fault is more likely a rift zone oriented E-W.

HOT AND COLD REGIONS OF THE SLOW-SPREADING SWIR (50-70°E): CONTRASTED ALONG-AXIS BATHYMETRY AND GRAVITY VARIATIONS

M. Cannat and C. Rommevaux-Jestin, CNRS-UPMC, Paris.
C. Deplus, CNRS-IPGP, Paris.
D. Sauter and V. Mendel, EOPG-CNRS, Strasbourg.

The axis of the Southwest Indian Ridge (SWIR; 1.7cm/yr) east of the Melville transform (61-70°E; mean depth 4800m) is 1700m deeper than west of the Gallieni transform (49-52°E) and 350 to 650m deeper than between Gallieni and Melville. This suggests that the crust is thinner, mantle densities greater, and sub-axial crust and mantle temperatures probably colder east of Melville. Correlations observed along the Mid-Atlantic Ridge (MAR) between the length of bathymetric segments (a bathymetric high bounded by 2 lows), segment relief, and segment-scale variations in Mantle Bouguer Anomaly (ΔMBA), are also present, if poorer, along the SWIR west of Melville. These correlations are absent, however, east of Melville: a few bathymetric segments, 34 to 82km-long and spaced by 70 to 270km, have high relief (1540 to 2630m) and ΔMBA down to -70mgal; the other segments have similar lengths, but moderately negative, to even positive ΔMBA. We propose that this lack of correlation is due to greater overall axial lithospheric thicknesses: 1) mechanisms believed to control axial depth at the MAR (isostatic response and axial valley formation) are complemented by the ability for the axial lithosphere to support loads such as large volcanic constructions; 2) moderate along-axis variations in magma (heat) supply do not significantly alter the rigidity of this thick lithosphere; 3) only larger variations in magma supply, producing isolated MBA lows, appear to overcome this thermal buffering effect. The difference in mean axial depth across Melville is only 350m: the transition from poor correlations to no correlation thus occurs within a small range of mean crustal thickness (of the order of 1km or less), and therefore presumably of axial temperature variations.

STRUCTURE OF THE TOP OF THE MELT BODY BENEATH THE EAST PACIFIC RISE AT 9°N FROM WAVEFORM INVERSION OF SEISMIC REFLECTION DATA

Jenny Collier and Satish Singh (BIRPS, Dept. of Earth Sciences, Cambridge University)

We have applied waveform inversion to multichannel seismic reflection data collected at the East Pacific Rise at 9°40′ N in order to determine the precise velocity structure of the magma body causing the AMC reflection. Our analysis supports the idea of a molten sill as previously suggested from forward modelling seismic data from this location. Our inverted solution has a 30 m thick sill with a P-wave seismic velocity of 2.6 km/s. Although not well constrained by the data we believe that the S-wave velocity in the sill is at or close to 0.0 km/s. The low P- and S-wave velocities in the sill imply that it contains less than 30 % crystals. The molten sill is underlain by a velocity gradient in which the P-wave velocity increases from 2.6 km/s to 3.5 km/s over a vertical distance of 50 m. The shape of our velocity-depth profile implies that accretion of material to the roof of the sill is minor compared to accretion to the floor. The underlying velocity gradient zone may represent crystal settling under gravity. We suggest that only material from the 30 m thick layer can erupt.

MANTLE FLOW AND SUB-MOHO MELT DISTRIBUTION BENEATH THE EAST PACIFIC RISE

R.A. Dunn, and D.R. Toomey (Dept. of Geological Sciences, University of Oregon, Eugene, OR, U.S.A.)

Tomographic images of the upper few kilometers of mantle beneath the EPR reveal significant azimuthal anisotropy and anomalously low seismic velocities. The anisotropy is consistent with two-dimensional mantle flow diverging from the spreading axis, while the anomalous isotropic seismic structure requires the bulk melt fraction to vary along axis by several percent. The seismic data were collected as part of an earlier experiment whose principle objective was to image the structure of the crustal magamatic system at 9°30'N. We use 200 Pn and 1360 crustal travel times to construct images of the velocity structure and the orientation and magnitude of azimuthal anisotropy in the upper mantle. The upper mantle structure is characterized by a low-velocity anomaly parallel to the rise with a cross-axis width, nearly 20 km, that is over twice the width of the low-velocity volume observed in the crust. The along-axis variation in the magnitude of the upper-mantle anomaly correlates with the segmentation of seafloor morphology and previously reported crustal images, implying that focussing of mantle melt at injection centers, distributed throughout a tectonically-defined ridge segment, gives rise to the fine-scale segmentation observed in crustal structure and seafloor geology.

STRAIN PARTITIONING AT A SLOW-SPREADING SEGMENT

J. Escartín, R. C. Searle, N. C. Mitchell (U. Durham, Durham, DH1 3LE, UK), P. A. Cowie, S. Allerton (U. Edimburgh, EH9 3JW, UK), C. MacLeod (U. Cardiff, CF1 3YI, UK)

Faulting and strain partition along a slow-spreading segment (29°N, MAR) are characterized using high-resolution TOBI side-scan sonar and bathymetry data. Mean spacing s and apparent heave h of faults is measured along EW backscatter profiles over inside-, outside- and segment-center crust. The zone of active faulting is limited to within 15 km from the ridge axis, and is characterized by closely spaced faults (s<500 m) with small heaves (h<150 m); off axis strain is localized to form larger faults (h>500 m) more widely spaced (s>1000 m). Apparent tectonic strain at inside-corners is ~0.17, and decreases to ~0.10 and ~0.09 at outside corners and segment centers. Variation in strain are accommodated along the axis by changes in faulting pattern between tectonic environments. At inside-corners faults have h>300m and s>1500 m, double of that found at outside-corners and segment centers. Larger faults at inside corners result from the linking of smaller closely spaced faults typical of segment centers. The variations in faulting pattern may correspond to enhanced strain localization at segments ends due to the presence of serpentinized peridotites and a thicker lithosphere than at segment centers.

SERPENTINIZATION AND THE STRENGTH OF SLOW-SPREADING LITHOSPHERE

J. Escartín, (U. Durham, Durham, DH1 3LE, UK), G. Hirth (WHOI, MA 02543, USA), B. Evans (MIT, MA 02139, USA)

Variations in faulting spacing and axial valley morphology along slow-spreading segments has been explained by a 'weak crust - strong mantle' lithospheric rheology. Recent experimental work, and re-examination of geological and geophysical data strongly suggest that the crust may be as strong as the mantle. Therefore alternative rheological models are required to explain changes in tectonic patterns. Strength versus depth profiles, calculated for conditions appropriate for slow-spreading ridges, indicate that serpentinization can reduce the integrated strength of the lithosphere by up to ~20%. The lowering of the friction coefficient due to serpentinization has a larger effect on fault spacing than changes in lithospheric thickness due to along-axis variations in temperature. If serpentinization occurs along fault planes, enhanced strain localization occurs. Consequently, the increase of fault spacing and throw at the end of segments can then be explained primarily by the influence of serpentinization, and secondarily by thermally induced changes in lithospheric thickness along the ridge axis.

HYDROACOUSTIC MONITORING OF THE DISTRIBUTION OF MAGMATIC ACTIVITY ON THE MID-OCEAN RIDGE

C.G. Fox (National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory, Newport, Oregon 97365 USA)

A primary influence in thermal variation in young oceanic crust is the relative frequency of magma injection at the mid-ocean ridge axis. Some of the factors thought to influence this process include the overall spreading rate, proximity to mantle hot spots, and the relative magma supply as reflected in the morphology of individual segments. Until recently there had not been a viable method for monitoring this important process, but since 1991, NOAA/PMEL has successfully monitored volcanic seismicity in the northeast Pacific Ocean using underwater acoustics and the U.S. Navy Sound Surveillance System (SOSUS). During that period, two injection episodes have been detected and verified by field observations along the <1,000-km ridge system. The eastern Pacific Ocean between 20°N and 20°S includes nearly 4500 km of the East Pacific Rise and an additional 2200 km on the Galapagos Rift with spreading rates that vary from 5-17 cm/yr, but can not be monitored using existing fixed hydrophone arrays. In March, 1996, NOAA/PMEL began routine monitoring of this area using autonomous, moored hydrophones. It is anticipated that through multiple years of monitoring, the relationship between magmatism and the various controlling factors can be rigorously tested.

Structure of 0.5- to 8.0-m.y. Old Oceanic Crust at 14°S on the East Pacific Rise

J. Grevemeyer, W. Weigel and C. Jennrich (Institut für Geophysik, Universität Hamburg, Bundesstraße 55, 20146 Hamburg)

In November/December 1995, during the *EXCO*-cruise the R/V Sonne shot several Ocean Bottom Hydrophone seismic experiments at the east flank of the East Pacific Rise south of the Garrett Fracture Zone. The overall objective of the OBH experiments was to investigate age-dependent variations in the structure of young oceanic crust created at a „superfast" spreading ridge. A particular goal was to study the increase of seismic velocities in extruded basalts comprising layer 2A.

Seismic refraction data were obtained along six 60 to 100 km long profiles on 0.5, 1.0, 1.5, 2.0, 5.0 and 8.0 m.y. old seafloor. Travel time and amplitude data from 17 OBHs were modelled using asymptotic ray theory to generate two-dimensional velocity models. We found that velocities in layer 2A increase from about 3.2 km/s to 4.3 km/s, while velocities in the sheeted dykes (layer 2B) and the gabbroic section (layer 3) remain constant. Forward modelling of PmP- and Pn-phases suggests that velocities within the upper mantle increase gradually from about 7.6 km/s to 8.0 km/s. The crustal thickness is between 5.5 to 6 km along the profiles. The most viable explanation for increasing velocities in uppermost oceanic crust is decreasing porosity due to filling of open void spaces with hydrothermally generated minerals. Increasing velocities in the upper mantle are suggested to be a temperature-controlled phenomenon.

AXIAL VOLCANIC RIDGE ARCHITECTURE: CLASSIFICATION & INTERPRETATION OF VOLCANIC & TECTONIC FEATURES FROM HIGH-RESOLUTION SONAR IMAGES OF THE MID-ATLANTIC RIDGE (24'N - 30'N)

James W. Head, III & L. Prockter (Dept. Geological. Scis., Brown Univ., Providence, RI 02912 USA), and Deborah K. Smith (Woods Hole Ocean. Inst., MA)

Recent high-resolution (10s of meters) side-scan sonar data of the inner valley floor of the Mid-Atlantic Ridge (MAR) between the Kane and Atlantis transforms (26°N-30°N) reveal details of volcanic features making up architectural elements of large-scale topography of axial volcanic ridges (AVRs). We have completed a detailed morphological study of AVRs to determine their characteristics and mode of formation. Extrusive volcanic features are subdivided into four morphological units: seamounts, linear hummocky ridges, hummocks and smooth sheet-like flows. The AVR main building blocks are linear hummocky ridges, which sometimes have associated seamounts. Using quantitative models for basaltic eruptions from dikes emplaced in the submarine environment, we compare predicted products with observed morphologic features. Inhibition of gas exsolution, lack of magma disruption, and hydrothermal effects combine to decrease magma rise speed and enhance cooling, leading to more rapid centralization of eruptions along the widest places in the dike. Dikes are predicted to initially feed eruptions from fissure vents, producing lines of hummocky ridges or discontinuous walls of pillow mounds. Centralization of activity to several adjacent vents then locally produces chains of hummocky bulbous mounds and can enhance the effusion rate at a single vent to produce larger volcanic edifices classified as seamounts. Widest dikes are predicted to produce smooth flows up to several km in length, which should pond in lows adjacent to the AVR. Observed morphologic features and dimensions are comparable to those predicted on the basis of volume fluxes implied by the widths of dikes observed on the seafloor and related environments.

HOTSPOT EFFECTS ON FAULTING ALONG THE GALAPAGOS SPREADING CENTER

E.E.E. Hooft, R. S. Detrick (WHOI, USA), J. Escartín (U. Durham, Durham, UK), J. P. Canales, J. J. Dañobeitia (CSIC, Spain)

The interaction of the Galápagos hotspot with the Cocos-Nazca ridge may control magma supply to the ridge as well as the thermal structure at the axis; both these effects influence faulting patterns. Faulting geometry and relative tectonic strain along the Galápagos spreading center are characterized from bathymetry, slope and curvature maps. The relationship between spreading rate (SR), distance to hotspot, and the faulting parameters are used to investigate processes controlling lithospheric thickness and strain partitioning. Near the hotspot tectonic strain and seafloor roughness are low, while outward facing faults are abundant. Fault spacing displays a weak dependence on SR, while the fault height is weakly dependent on both SR and hotspot distance. Lithospheric thickness, as indicated by changes in fault spacing, is mostly controlled by changes in SR, with a weak hotspot influence. However, the hotspot increases the ratio of magmatic to tectonic strain, and results in smoother terrain (low seafloor roughness) and fewer faults. Away from the hotspot outward facing faults are scarce, consistent with cooling and thickening of the lithosphere. The rate of thickening may be reduced in the presence of the hotspot, as indicated by the increase of outward facing faults.

SLIP SURFACES ON INNER CORNER HIGHS ON THE ATLANTIS TRANSFORM

B. Janssen, J.R. Cann, D.K. Blackman (University of Leeds, Department of Earth Sciences, Leeds LS2 9JT, UK)

We present recent high-resolution data from the Atlantis Fracture Zone which is situated on the Mid-Atlantic ridge at 30 degrees north. Multibeam bathymetry and Tobi side scan sonar yield unprecedented geographically well constrained geological maps of the inner corner highs. An important discovery is the existence of corrugations up to 8 km long on active and fossil inner corner highs that tilt towards the axial spreading valley. These corrugations show on both low-resolution multibeam bathymetry as well as on high-resolution sidescan sonar. The corrugated surfaces are readily identified as slip surfaces but are virtually horizontal and it is therefore difficult to explain how slip could have taken place.
At present, two models aim to explain these observations of low-angle slip surfaces. It has been proposed that landslides occur in the vicinity of axial valleys. Our observations seem broadly consistent with landslide morphology. The slip-surfaces would have been backtilted and de-activated in the process of uplifting of flanks. Secondly, some believe that extension occurs by low-angle faulting. The observed slip-surface would then be the outcrop of such a detachment fault. Apart from the new imagery we present some simple quantitative models to assess the merits of both models. We use mass shedding and friction considerations to show under what conditions slip can have have taken place.

EXCHANGE OF THERMAL ENERGY BETWEEN CRUST AND OCEAN ON THE EASTERN FLANK OF THE EAST PACIFIC RISE AT 15°S

N. Kaul, H. Villinger (University of Bremen, Dep. of Geosciences, PO Box 330440, 28334 Bremen, Germany)

A detailed study of heat flow through the ocean floor was carried out in a 720 km long transect from the East Pacific Rise (EPR) to the east. This transect covers a crustal age of 0.5 - 8 m.y.. Within the first few million years, the crust looses most of its thermal energy by conduction and convection processes. Both processes are controlled by porosity of the upper crust (layer 2A), sediment coverage, seafloor topography and thermal conductivity. To takle these superimposed influences on heat flow an integrated approach was carried out, using reflection seismics, refraction seismics, sediment echosounder, swath bathymetry, temperature and thermal conductivity measurements. The results show, why local variations of these parameters have a greater effect on heat flow values than the regional trend.
Convective heat transport at mid ocean ridges takes place in spectacular form as black smokers or unspectacular but very effective as a diffuse flow. It is difficult to detect this diffuse flow of material and energy through the sediments, but we show that a thermal signal within the watercolumn is traceable.

STAGES OF FORMATION OF MAGMA CHAMBERS AND HYDROTHERMAL CELLS ON SLOW-SPREDING MID-OCEANIC RIDGES

Kharin G.S. (Institute of Oceanology, Atlantic Department, pr. Mira 1, 236000 Kaliningrad, Russia)

On the slow-spreding mid-oceanic ridges we allocated the following stages of formation magma chambers: filling, voiding and caving (Kharin,1991). The duration of stages depends on speed of receipt emerging diapir fold, contents in them of the melt, speed of the spreding. The formation of the convective hydrothermal cell depends stage magma chamber. It arises and functions in stage of filling magma chamber. In stage voiding it gradually disappears, and in stage caving the tectonic movements of the new oceanic crust blocks completely it liquidate. In this stage the sea water penetrates the most deeply, up to the mantle basis of the chamber, and causes the strong alternations of the magmatic rocks.

DETAILED CRUSTAL MAGNETIZATION OF THE REYKJANES RIDGE BETWEEN 57°30'N AND 62°30'N

S.-M. Lee and R.C. Searle (Univ. of Durham, Dept. of Geological Sciences, Durham DH1 3LE, England)

We present the preliminary results of a three-dimensional inversion of the magnetic anomaly data collected during a cruise to the Reykjanes Ridge between 57°30'N and 62°30'N in June-July of 1994 onboard RRS *Charles Darwin*. We assume a uniform thickness magnetic source layer with direction of magnetization corresponding to the geocentric axial dipole field. Scalar magnetic fields, measured using a proton precession magnetometer, were corrected for diurnal variations using digital magnetograms of nearby land-based stations, which reduced the rms crossover error from over 130 nT to 84 nT. To minimize the edge effect and examine the long wavelength features, we utilized existing regional field and bathymetric information of the region outside our survey area, and thus the actual inversion was performed over a much larger area (55°N-65°N and 37°W-21°W). Magnetic field anomalies are almost linear with little variation in the amplitudes along the ridge, although the axial depth of seafloor decreases steadily from approximately 2600 m at 57°30'N to 500 m at 62°30'N. This is probably because the Earth's field at this region is almost perpendicular to the strike of ridge axis. We examined the correlation between short wavelength magnetization anomalies and distribution of en echelon Axial Volcanic Ridges (AVRs). On average the AVRs are displaced slightly (2-3 km) to the northwest compared to the axis of Brunhes normal magnetization zone, although AVRs tend to coincide with individual peaks within this magnetization zone.

DEATH AND TRANSFIGURATION OF A TRIPLE JUNCTION IN THE SOUTH ATLANTIC

M. Ligi (IGM-CNR, Via Gobetti 101, Bologna, Italy)
E. Bonatti (IGM-CNR and Lamont Doherty Earth Observatory, Palisades, N.Y., USA)
G. Bortoluzzi, G. Carrara, P. Fabretti, D. Penitenti and M. Terenzoni (IGM-CNR)
D. Brunelli and A. Cipriani (Dip. di Geologia, Univ. di Padova, Italy)
D. Gilod, A.A. Peyve, S. Skolotnev and N. Turko (Geology Institute, Russian Academy of Sciences, Moscow, Russia)

Three major lithospheric plates, Antarctic, South American and African, meet in the South Atlantic near Bouvet Island. Morphostructural and magnetometric analysis of this region has revealed complex, fast-evolving interactions between the Mid Atlantic Ridge (MAR), the southwest Indian Ridge (SWIR) and the American Antarctic Ridge (AAR), as they converge towards the Triple Junction (TJ). A major magmatic pulse has built within the last 1 m.y. a new, swollen segment of the SWIR ("Spiess Ridge") that propagates towards the eastern MAR flank at an estimated rate between 4 and 5 cm/y, disrupting a ridge/ridge/ridge (RRR) configuration that about 2 m.y. ago had replaced a ridge/transform/transform (RFF) TJ. A new RRR TJ will be established about 70 km north of the former one when, probably within the next 1 m.y., the propagating SWIR/Spiess segment will impact with the MAR. The AAR will take advantage of the MAR/SWIR duel by capturing a ~ 70 km stretch of former MAR, while the Antarctic plate will increase its size. We have thus obtained a rare snapshot of the recent death of a TJ, and the imminent birth of a new one.

THE EFFECT OF MANTLE FLOW AROUND THE SUBDUCTING SLAB ON SPREADING BEHIND THE SOUTH SANDWICH ARC

R. A. Livermore and **R. A. Livermore** (British Antarctic Survey, High Cross, Madingley Road, Cambridge, England CB3 0ET)
N. J. Bruguier (British Antarctic Survey, High Cross, Madingley Road, Cambridge, England CB3 0ET)

Recent marine geophysical surveys of the East Scotia Ridge show that it is comprised of nine active segments, eight of which exhibit median valleys. The exception occurs toward the northern end of the Ridge, and is a southwards-propagating axial high, complete with seismic magma chamber reflector. At the southern end of the Ridge, a central axial high is developed within the shallow median valley, suggesting recent enhancement of the magmatic budget. There is evidence that, while the mantle beneath most of the ridge is anomalously cool, resulting in the formation of a median valley even at spreading rates of 60-70 km/Ma, the end segments are influenced by the influx of slightly enriched mantle. This occurs as South Atlantic mantle is displaced by the retreating slab, and flows around the slab ends, perhaps becoming charged with volatiles in the process. The enhanced melting which results is sufficient to reduce crustal strength and, in the north at least, to form a crustal magma lens.

CRUSTAL STRUCTURE OF THE SOUTHWEST INDIAN RIDGE AT THE ATLANTIS II FRACTURE ZONE

T. A. Minshull (Bullard Laboratories, Madingley Road, Cambridge CB3 0EZ, U. K.), M. R. Muller, C. J. Robinson, R. S. White and M. J. Bickle

Crustal thickness determinations at very slow-spreading ridges constitute a critical test for models of mantle melting between spreading centres, since the predictions of various models diverge at full spreading rates less than about 20 mm/yr. We have analysed a combined geophysical and geochemical dataset from the Southwest Indian Ridge (spreading rate 15 mm/a) at the Atlantis II Fracture Zone, at a location where Ocean Drilling Program Hole 735B drilled directly into 500 m of isotropic gabbro thought to represent the lower oceanic crust. A wide-angle seismic experiment across and along the transverse ridge of the fracture zone, and coincident gravity profiles, show that the crust is about 4 km thick thoughout most of the survey area, but is slightly thinner beneath the fracture zone valley and thicker beneath the ODP site. Major element compositions and rare earth element inversions on basalt glasses dredged from the rift valley and from the conjugate site to 735B, where the unroofed upper crust is thought to lie, indicate a melt thickness of 3-4 km, suggesting a magmatic origin for most or all of the geophysically constrained crustal section. However, beneath Hole 735B, where the seismic crust is thicker, and the upper crustal section has been removed, we infer the presence of 2-3 km of partially serpentinised peridotite above the Moho. The thin magmatic crust is consistent with thermal models in which melt production at very slow-spreading ridges is inhibited by conductive cooling.

EXTENSIVE OBLIQUE FAULTING ADJACENT TO THE CONRAD AND BOUVET FZS NEAR THE BOUVET TRIPLE JUNCTION

NC Mitchell (Dept of Geol. Sciences, Durham Univ., DH1 3LE, UK), RA Livermore (British Antarctic Survey, Cambridge) and SM Lee (Durham Univ.)

The Bouvet triple junction has been proposed to have evolved as a ridge-fault-fault (RFF) type between 20 and 10 Ma, with the southernmost Mid-Atlantic Ridge (MAR) connected to the Bouvet and Conrad fracture zones. We report mapping of seafloor immediately north of these two fracture zones, along the fossil ridge-transform intersections, with the HAWAII-MR1 sidescan sonar. The sonar images reveal that MAR fabrics on the Bouvet and Conrad sides are almost parallel to each other, confirming that the triple junction was probably RFF. The ridge-transform intersections either side of the MAR were different however; the Conrad transform is almost perpendicular to MAR fabrics while the Bouvet forms an acute 60° angle with them. These MAR fabrics are extensively cross-cut by oblique normal faults over most of the 400 km surveyed along both fracture zones, and most intensely within the acute Bouvet side. Similar oblique faults have been found at other fracture zones, but the faults found here are more numerous. Although we cannot yet rule out tranform-perpendicular extension as a cause, we speculate that they may be related to the acute ridge-transform geometry and perhaps to transform frictional resistance which has been proposed to explain oblique fabrics elsewhere.

EVOLUTION OF FAST-SPREAD OCEANIC CRUST - CONSTRAINTS FROM OFF AXIS SEISMIC IMAGES

T. J. Reston (Geomar, Wischhofstr. 1-3, 24148 Kiel, Germany),
C. R. Ranero, I. Belykh (Geomar, Kiel, Germany)

It is generally thought that oceanic crust formed at half spreading rates of greater than about 35 mm/yr is internally poorly reflective. This paradigm is shown to be incorrect by new images from the NW Pacific and other regions. These show that the oceanic crust is characterised by numerous reflective structures. Most prominent are lower crustal reflections which dip consistently ridgeward and appear to stop abruptly at the crust-mantle boundary (CMB). We interpret the lower crustal reflections as layering formed at the spreading centre, consistent with numerical models of spreading centre evolution (Phipps Morgan and Chen,1993, JGR). The data also reveal sub-horizontal features in the upper crust, about 600-800ms beneath the top of basement. These reflections are generally positive polarity, and appear to be reflections from a single interface. We tentatively identify these as coming from the layer 2/3 boundary, possibly locally a sharp tectonic contact (detachment) formed near the spreading centre at the base of the deforming brittle upper crust. Finally, discrete reflections (interpreted as faults or shear zones), dipping both towards and away from the paleo-spreading centre, traverse the entire crust and in one location appear to offset the CMB.

EXTENT OF ACTIVE FAULTING ABOUT THE GALAPAGOS SPREADING CENTRE

NC Mitchell and RC Searle (Dept of Geol., Durham Univ., DH1 3LE, UK)

High rates of equatorial pelagic sedimentation result in steep accumulations over fault scarps around the Galapagos spreading center. Profiler records from the Scripps Deep Tow show that these deposits generally lack evidence for slides, such as concave slide scars or irregular deposits at scarp bases. We propose that significant seismogenic movement on these faults would cause sediment sliding or other bulk mass-wasting, and therefore the locations of stable slopes can be used to constrain the limit of seismogenic faulting around the spreading center. Stable sediment deposits occur on crust between ~500 ky and 2 my, which is the oldest seafloor of the survey, so faults are probably not seismogenic in crust of this age range. We use a simple slope stability model to infer the minimum horizontal ground acceleration required to cause failure, which is generally 0.1-0.2g. Strong motion data for continental earthquakes of magnitude 4-5 show that they may produce accelerations of 0.1-0.2g within distances of 5-10 km. Given this seismic sensitivity and the locations of stable slopes, we predict that faults are probably aseismic on seafloor older than ~400 ky. Sediment scarps become increasingly sensitive to ground shaking with seafloor age as accumulations steepen and thicken, so long-term seismicity on ridge flanks could potentially be assessed by mapping slides and stable slopes with suitable deeply towed instruments. This may have applications, for example, for studying the seismic effects of plate cooling.

GEOPHYSICAL EVIDENCE FOR A CRUSTAL MAGMA BODY BENEATH THE SLOW SPREADING MID-ATLANTIC RIDGE.

D.A. Navin, C. Peirce and M. A. Inglis (University of Durham.)
S. C. Constable (Scripps Institution of Oceanography, UC San Diego)
A. White and G. Heinson (Flinders University of South Australia)
L. M. MacGregor and **M. C. Sinha** (University of Cambridge.)

In October 1993 we carried out a multi-component geophysical experiment on the axis of the Reykjanes Ridge centred on 57°45′ N. The data collected included: wide angle and normal incidence seismic profiles both along and across the axis of an axial volcanic ridge (AVR) segment; a controlled source electromagnetic (CSEM) experiment; and a magneto-telluric (MT) sounding on and around the AVR axis. We interpreted the MT data using 1- and 2-D forward modelling and regularised inversion to obtain resistivity-depth structure from the sea floor to a depth of approximately 100 km. The results show a very conductive crust beneath the AVR; moderately high resistivities in the uppermost mantle; and decreasing resistivities beneath 40 to 50 km depth. We modelled the seismic data using 2-D synthetic seismogram techniques. They show both a restricted region of extremely low velocity, whose top surface coincides with a seismic reflector, at a depth of 2.5 km beneath the AVR axis; and a larger region surrounding this with moderately depressed P-wave velocities. We modelled the CSEM data in terms of 2-D resistivity structures. A region of very low resistivity, coincident with the seismic low velocity zone, is required to fit these data. The results represent compelling evidence for the first crustal magma body to be detected beneath a slow-spreading ridge.

REFLECTION SEISMIC DEPTH IMAGES OF CRUSTAL STRUCTURES OF ATLANTIC OCEANIC CRUST

O. Ruoff (GEOMAR Wischhofstr. 1-3, D 24148 Kiel, Germany).
T.J. Reston, C.R. Ranero (GEOMAR, D 24148 Kiel, Germany).
J.J. Dañobeitia (CSIC; Jaume Almera, Barcelona, Spain)

Multichannel seismic reflection images of crustal structures of North/Central Atlantic oceanic crust constrain the tectonic evolution of the crust at slow-spreading mid-ocean ridges. We present results from prestack depth migration of reflection data collected in the Canary basin west of North Africa. The data chosen cross oceanic crust of comparable age where the igneous basement exhibits a strong relief and continous intrabasement reflections were found. The key observations, are gently-dipping, sub-horizontal, west- and east-dipping reflectors. We interpret the large-scale westward dipping reflectors as faults, being created only a few million years after the accretion of the new oceanic crust. Sub-horizontal to gently-dipping reflections may in some cases be detachment faults, in others hydrothermal boundaries. Our interpretation of the east-dipping reflections is less certain and will be discusssed at the meeting. Our data contributes to the discussion about the tectonic style during spreading at slow spreading centres.

FIRST CORRELATION BETWEEN SEISMIC LAYER 2A AND EXTRUSIVES ON THE MID-ATLANTIC RIDGE

J.R. Smallwood and R.S. White (Bullard Laboratories, University of Cambridge, UK.)

Seismic refractions recorded on a 48-channel, 2.4 km hydrophone streamer have been used together with Ocean Bottom Hydrophone and sonobuoy records to construct a model of the crustal velocity structure on the Reykjanes Ridge from 61–62°N (R.R.S. *Charles Darwin* cruise 70, 1992). Streamer refractions define the base of seismic Layer 2A, the shallowest layer of the igneous oceanic crust. Layer 2A is commonly interpreted as the extrusive layer for the youngest crust on the East Pacific Rise.

The P-wave velocity at the sea-floor is 2.45 ± 0.3 km s^{-1}, and the refraction velocity from the base of Layer 2A is 3.3 ± 0.4 km s^{-1}, below which a vertical velocity gradient of 1 s^{-1} takes the velocity to 6.8 ± 0.2 km s^{-1} at a depth of 4 km below the sea-floor. Layer 2A varies in thickness from 100 to 600 m with a mean of 400 m along the ridge axis, with thickness variations related to the axial volcanic ridges at which volcanism occurs at the sea-floor.

Magnetic data was taken from the R.S.S. *Charles Darwin* cruise 87 (1994) dataset. The magnetic anomaly varies in amplitude dramatically along strike of the Central Magnetic Anomaly High. We here demonstrate a correlation between the magnetic anomaly data and the magnetic signature of the seismically measured Layer 2A, a correlation which suggests that seismically defined Layer 2A on the ridge axis is coincident with the extrusive layer.

TECTONIC–MAGMATIC CYCLES AT THE SLOW SPREADING MID-ATLANTIC RIDGE

M. C. Sinha and L. M. MacGregor (University of Cambridge)
D.A. Navin, C. Peirce and M. A. Inglis (University of Durham)
S. C. Constable (Scripps Institution of Oceanography, UC San Diego)
A. White and G. Heinson (Flinders Univ. of South Australia)

The results of a multi-component geophysical experiment on an axial volcanic ridge (AVR) segment of the Mid-Atlantic Ridge, at 57°45′ N, provide clear evidence for the presence of a large crustal magma body. The experiment included: wide angle and reflection seismic profiling; controlled source electromagnetic (CSEM) sounding; and magneto-telluric (MT) sounding. The experiment was carefully targeted on a segment of the ridge that shows clear signs of recent volcanic activity at the sea floor. Both the seismic and CSEM studies imaged the melt body. The MT results confirm the low crustal resistivities beneath the axis. There has been much debate on the question of whether or not significant melt accumulations are formed beneath slow spreading ridges. We argue that the balance of evidence is now strongly in favour of a mechanism of crustal accretion that involves extensive but short lived crustal magma bodies. We estimate that the melt body at 57°45′ N contains sufficient magma to feed crustal accretion for approximately 20,000 years; but that its lifetime as a molten body must be much shorter than this. We conclude that accretion is cyclic with a period in excess of 20,000 years, and shall explore the implications of this for crustal and mant le thermal structure beneath the ridge.

AMPLITUDE ANALYSIS OF SEISMIC REFLECTION DATA FROM THE CANARY BASIN - IMPLICATIONS FOR THE EVOLUTION OF THE OCEANIC CRUST

S. Voss (GEOMAR Wischhofstr. 1-3, D-24148 Kiel, Germany)
T.J. Reston, C.R. Ranero, O. Ruoff (GEOMAR, D-24148 Kiel, Germany)

Analysis of multichannel seismic reflection data can constrain the evolution of the oceanic crust. In particular, determining the reflection coefficient of intracrustal reflectors provides information about the impedance step between two layers and hence the velocity and density difference between them. We have applied such analyses to two data segments from the Canary Basin, a region where bright lower crustal reflectivity has been reported. After standard processing, in which the true amplitude information was kept, the seismic analysis was carried out for both near-offset and far-offset stacks and also for a near-offset poststack time migration to ensure the absence of divergence effects. The seismic analysis begins with a comparison of both seafloor reflection and the seafloor multiple to calibrate the system and determine a reflection coeffcient for the seafloor. We then compare the amplitude of the intracrustal reflections to the seafloor to determine the reflection coefficient of the deep reflectors. After applying spherical divergence- and Q-corrections the envelope functions of both seafloor and deep crustal reflector have been compared. We have also used modelling to confirm our results. Our results constrain the origin of reflections from the lower oceanic crust and hence also spreading centre processes.

Tectonic Evolution of MAR and it's Flanks Between Atlantis and Kane Fracture Zones based on the 3-D Gravity Modeling

Andrey V. Zayonchek 1, Sergei P. Maschenkov 2
1 Geological Department of St. Petersburg State University, Russia
2 VNIIOkeangeologia, St. Petersburg, Russia.

The poster presents the results of the three-dimensional gravity modeling which was carried out for the large extension area from the Mid Atlantic Ridge between Kane and Atlantis Fracture zones to the magnetic anomaly 25 (40 M.y.). We used 3-D gravity modeling to computed mantle Bouguer anomaly (Kyo and Forsyth, 1988). Three different models of the oceanic crust structure have been evaluated. Residual mantle Bouguer anomaly (RMBA) were calculated in accordance with density model considering the lithosphere/age dependence. The applying of the Parker's (1973) inversion to the RMBA shows that the real explanation of observed gravity patterns is not only variations of crustal thickness (Lin et.al., 1990) but the density structure of the entire lithosphere. This stude demonstrates a new view to the tectonic evolution well studded region connected with crust/mantle interaction.

SE28 Lithospheric structure and seismicity at convergent margins

Convener: Flüh, E.R.
Co-Conveners: Carbonell, R.; Cordoba, D.

SOME MAJOR PROBLEMS OF THE POST-CRETACEOUS STRUCTURAL EVOLUTION OF THE CAUCASUS.

Bombolakis, E.G., (Dept. Geology & Geophysics, Boston College, Chestnut Hill, MA, U.S.A.)
S. A. Adamia, (Director, Geological Institute Acad. Sci. of Georgia, Tbilisi, Georgia)
E. Dolginov, (Head, Geology Dept., Russian Peoples' Friendship Univ., Moscow, Russia)

Two major problems are whether the Caucasus is undergoing initial stages of continental collision, and whether the Borzhomi-Kazbeg fault is actually a major crustal fault zone that separates the eastern Great Caucasus structurally from the western Great Caucasus. A string of intermontane basins and the Lesser Caucasus extend from the Caspian Sea to the Black Sea along the southern border of the Great Caucasus. Tethys subduction reportedly took place south of the Turkish, Lesser Caucasian, and Iranian continental blocks, with a marginal sea developed between these blocks and the Russian Platform. The Arabian plate began to migrate northwards and the old marginal sea basin closed first at the northern border of the Lesser Caucasus in the middle Miocene, followed by continental collision between the Arabian and Eurasian plates, with lateral ejection of the Anatolian plate to the west, and of the Iranian plate to the east. However, the structure of the basins is controversial: steep faults and open folds versus nappe structure. Three transects will be presented regarding these major problems.

Recent results on seismic activity in Southern region of Portugal and the Atlantic adjacent zone

José Fernando Borges and **Augusto J. S. Fitas**, Departamento de Física, Universidade de Évora, Apartado 94, 7001 Évora, PORTUGAL
Maria Luisa Senos and Fernando Carrilho, Instituto Nacional de Meteorologia, Rua C ao Aeroporto, 1700 Lisboa, PORTUGAL

The Southern Portugal is a region of significant seismicity and it can be divided in two areas: atlantic underwater adjacent zone and continental zone. The first one is characterized by a more intense instrumental and historical seismic activity which is strongly correlated to the border zone between Eurasian and African plates, where the most significative seismic production takes place and is recorded in Iberian peninsula and North Africa. The second zone is characterized by a seismicity of magnitudes often less than 5, one of the epicenters concentration area is the south coast. There are instrumental and historical data which shows that this last zone is crossed by several tectonic faults with present activity. The analysis of seismic instrumental data collected by two seismological arrays placed in southern region of Portugal and covering an observation period of six months, are presented. It will be enphasized in this study the time and space distribuition of all events, focal mechanism and possible tectonic correlation. A source inversion method based on seismic waveforms is used because of the poor azimutal coverage of seismic arrays.

SEISMIC IMAGES OF THE CRUST BETWEEN THE JALISCO BLOCK (WESTERN MEXICO) AND THE RIVERA-PACIFIC PLATES.

D. Cordoba and M. Romero (Dpt. of Geophysics, UCM, Madrid, Spain)
J.J. Danobeitia, R. Carbonell and T. Minshull (Dpt. of Geophysics, CSIC-Institute of Earth Sciences, Barcelona, Spain)
F.J. N=A3=A4ez-Corn=A3 (CUC and CUSH, Universidad de Guadalajara, Mexico)
L. Delgado and F.A. Nava (CICESE, Ensenada, B.C., Mexico)
F. Michaud, Ph. Charvis (Orstom, Paris VI-CNRS, Villefranche-s-m, France)

During April 1996 a seismic network of 10 portable stations was installed at the NW of the Jalisco Block and one station in the Maria Cleofas Island (Western Mexico: 105-107=A7W, 19-22=A7N). These equipments recorded onshore the airgun shots carried out by the Oceanographic Vessel HESPERIDES as part of the multidisciplinary CORTES-P96 programme. In this area, a total of seven 50-100 km long wide angle refraction profiles (six almost perpendicular to the Rivera Trench and one transect from the Banderas Bay to the Maria Cleofas Island) imaged the crust in a region where abnormally high seismicity has been observed during the last years. In addition to the onshore recording, the airgun shots were also recorded also by a network of 10 OBS on both sides of the Rivera Trench and by the multichannel seismic equipment of R/V HESPERIDES. The high density of onshore-offshore seismic recording (one seismogram/80 m) and the sharp vertical reflection seismic sections permited to model the fine crustal structure at the convergence of tectonic plates and the thinning of the continental crust to the Marias Island Scarp. Vertical and wide angle reflection data show a small and deformed accretionary prism of small dimensions and a Benioff zone dipping 12=A7W. The continental crust thins from 25 km (North of Banderas Bay) to 10 km at the West of Maria Cleofas Island (80 km from the coast line).

LITHOSPHERIC STRUCTURE OF THE WEST MEXICAN CONTINENTAL MARGIN. CORTES-96 PROJECT

J.J. Danobeitia and R. Carbonell, R. Bartolome (Dept. Geophysics, CSIC-Institute of Earth Sciences, 08028 Barcelona, Spain)
D. Cordoba (Dpto. Geofisica, Universidad Complutense, 28040 Madrid, Spain.)
L. Delgado (Div. Ciencias Tierra, CICESE Ensenada, Baja California, Mexico)
F. Michaud, Ph. Charvis (Orstom, Paris VI-CNRS, Villefranche-s-m, France)
F. Nunez-Cornu (CUC and CUSH, Universidad de Guadalajara, Mexico)
T. Minshull (Bullard Lab, University of Cambridge, CB3 0EZ, U.K.)

In spring 1996 a geophysical survey was carried out along the West Mexico Continental Margin. The marine survey was accomplished with the B/O Hesperides, R/V Altair and Humbolt. Deep crustal and upper mantle structures were imaged by CMP profiling, and coincident velocity information obtained with OBS along the MCS profiles. The transition from oceanic to continental crust were sampled by deploying 35 portable landstations (5 km spacing) 50 km inland. Moreover, swathmapping provides a good superficial coverage that delineate the main structural features. Preliminary stacked profiles image the subducting oceanic slab beneath North America, showing smooth angles of subduction with a relatively thick sedimentary sequence (0.5-1.0 s), with indications of a sudden rupture south of Bahia Banderas. There is a deformed accretionary prism of small dimensions decreasing in size from south to north. At the Rivera plate beneath the Jalisco block, the seismic images display west of the trench, at 2 s beneath the top of the oceanic basement, a prominent and continuous reflection that we associated with the Moho discontinuity.

NEW SEISMIC IMAGES OF THE CASCADIA SUBDUCTION ZONE FROM CRUISE SO108 - ORWELL

E. R. Flueh (GEOMAR, Wischhofstr. 1-3, 24148 Kiel, Germany)
M. Fisher (USGS, Menlo Park, Ca), J. Bialas (GEOMAR), J. Childs (USGS, Ca), D. Klaeschen (GEOMAR), Nina Kukowski (GEOMAR), T. Parsons (USGS, Ca), D. Scholl (USGS), U. ten Brink (USGS, Woods Hole, Ma), A. Trehu (Oregon State, Corvallis, Or) , and N. Vidal (GEOMAR)

The Cascadia subduction zone is often described as the `normal or classical' accretionary margin. Modern results, however, show that the structural style changes frequently and abruptly along this margin. All extremes from rapid accretion to tectonic erosion are present, and sometimes gradual changes from one to the other. Cascadia is also vulnerable to geohazards such as large earthquakes, tsunamis and volcanic eruptions. New results indicate, that only 300 years ago a large earthquake devastated this region and the discussion about the eminance of the next earthquake and ist possible magnitude (8.0 or 9.5?) is continuing. To better resolve this question, the geometrie of the downgoing plate has to be better constrained. Due to the lack of small earthquakes this wasnot possible hithero.
During cruise SO108 - ORWELL (Oregon and Washington Exploration of the Lithosphere - a geophysical Experiment) in a joint effort between GEOMAR and the US Geological Survey seismic work was made on the Oregon and Washington margins. In total 13 near-vertical refelction profiles with a total length of 1385 km and 7 wide-angle profiles with 116 OBH/OBS positions were recorded.
Accretion of the thick sediment cover of the Juan de Fuca plate is accomplished along 5 to 6 seeward dipping thrusts. The dip of the plate is rather moderate, less than 4°, and can be followed on the seismic sections to the coast at 13 km depth.

NUMERICAL MODELLING OF THE STRESS AND STRAIN FIELDS IN ACCRETIONARY WEDGES

M.-A. Gutscher, N.Kukowski, D. Mann, (GEOMAR, Kiel, Germany)

Deformation and stress in accretionary wedges are modeled using the finite element method. A depth-dependent Coulomb rheology is applied since it is the most appropriate for the brittle failure of sedimentary and upper crustal rocks (< 10 km depth). The model dimensions and material parameters are scaled to actual accretionary wedges. Boundary conditions include a deformable backstop, held fixed at its arcward side, the body forces (gravity, buoyancy) and a displacement boundary condition along a rigid basal surface. Alternatively, the subducting oceanic crust is modeled as a separate body (ca. 6 km thick plate) with the appropriate rheology. Based on results from analog experiments, the influence of the strength of the basal detachment on the evolution of the stress field was tested.
The displacement trajectories modeled indicate that for a weak detachment layer, material addition occurs distributed across a broad frontal region. In contrast, a strong basal detachment causes predominantly plate parallel motion and material addition primarily in the basal region. The initial taper of the wedge also influences the location of stress accumulation. Stress concentrations are highest within the subduction channel. The thickness of this layer of subducting sediment was varied from 10 -100 % of the sedimentary section at the trench. The principal compressive stress (σ_1) dips steeply trenchward (ca. 30°) for a strong basal detachment and succesively more shallow for a weaker detachment.

DICONTINUOUS NATURE OF THE LOWER PART OF THE SOUTH AMERICAN WADATI-BENIOFF ZONE IN THE ARICA ELBOW REGION

V. Hanuš, A. Špičák, J. Vaněk (Laboratory of Global Tectonics and Metallogeny c/o Geophysical Institute, Czech Academy of Sciences, Boční II 1401, 14131 Praha 4, Czech Republic

The Arica Elbow region represents that part of Andean South America where the Peru-Chile trench changes its strike from the azimuth of 150° to 190°. The area under study is roughly bounded by latitudes 17°S and 23°S. The shape of the Wadati-Benioff zone was investigated by the distribution of ISC hypocenters from the period 1964-93. On the basis of a system of 22 cross-sections perpendicular to the trench axis and of a map of epicenters a fingerlike shape of the lower part of the Wadati-Benioff zone beneath the aseismic gap was found. The slab length of the northern sections shows small changes around 350 km, expressive length oscillations between 350 and 750 km in the neighbouring central sections and a constant value of 650 km in the southern sections. The dip and slab thickness are practically constant in all sections.

Reflection and refraction imaging of the Alaska Margin and constraints on rate of tectonic shortening

R. von Huene, D. Klaeschen (GEOMAR, U Kiel, Wischhofstr. 1 - 3 , D-24148 Kiel, Germany, e-mail: rhuene@geomar.de

Combined reflection and refraction seismic data across the Alaska Trench and Kodiak shelf yields a true-scale cross section. Velocities from pre-stack depth migration of reflection and wide angle seismic data agree within ~ 5% precision. Line and volume section balancing were used to restore the past 2,5 to 3 Ma of accretionary tectonics. The 44 km wide lower slope is composed of sediment sections that once stretched to ~ 75 km across the oceanic plate. When integrated over time, the peak contraction over the base of the slope falls off to less than half that rate at the back stop. Landward, the upper slope has contracted at only 10% of the peak rate. Once the distribution of strain rates across the margin (over 1 Ma) can be compared to the co-seismic deformation from the 1964 Alaska earthquake, the rheological response of the crust during a great earthqake may be better constrained for modeling.

TICOSECT 3D OBS/OBH SURVEY OFF CENTRAL COSTA RICA

K. McIntosh, F. Akbar, C. Calderon, S. Operto, P. Stoffa, G. Christeson, and T. Shipley (Univ. of Texas Inst. for Geophysics, 8701 N. Mopac, Austin TX 78759) A. Stavenhagen, E. Flueh, and J. Bialas (GEOMAR, Wischhofstr. 1- 3, 24148 Kiel, FRG)

Data acquired during the spring 1995 TICOSECT project included OBS/OBH data offshore and onland seismic data along three transects of the Pacific margin of Costa Rica. The concept was to investigate the subduction processes where three distinctly different domains of the Cocos Plate underthrust the same margin: relatively smooth crust to the north, seamount dominated crust off central Costa Rica, and the Cocos Ridge in the south. In particular we were interested in the different deformation styles of the upper plate and in how subducting plate morphology affects earthquake generation and the location of the seismogenic zone. Off central Costa Rica it is clear that subducting seamounts deform the trench slope. However, the fate of these seamounts at greater depth has not been documented nor has their relation to earthquake activity. We performed a 3D OBS/OBH survey off the southeastern edge of the Nicoya Peninsula covering an area 9 km by 35 km, which includes the epicenter of the 1990 M=7.0 earthquake. Bathymetric data also suggest that a seamount may have recently subducted beneath this area. Using the OBS/OBH data we have developed a 3D velocity model of the survey area and created preliminary images using a Kirchhoff-type, 3D, pre-stack, depth migration. We are now in the process of interpreting and evaluating these images and preparing for a revised migration.

REFRACTION SEISMIC MODELLING OF THE SUBDUCTION ZONE OFF NORTH SULAWESI (INDONESIA)

Kopp, C., Flüh E. R., Bialas J., Hinz K., Fritsch J., Neben S. and GIGICS working-group

The project GIGICS under leadership of BGR (Hannover, Germany) investigates the structure, composition, and age of the oceanic crust in the Celebes Sea, and in particular the subduction mechanisms at its convergent margins.
North of Sulawesi three parallel refraction lines were recorded with GEOMAR-OBH perpendicular to the strike of the subduction zone and coincident with reflection lines recorded by BGR.
The latest results from refraction seismic velocity-modelling will be presented and combined with reflection data using different methods. By determining seismic velocities of some remarkable structural elements in the accretionary wedge new conclusions can be made for geologic and tectonic interpretation.
The complex wedge is dominated by thrusts and detachments. In refraction as well as in reflection data some hints of high velocity blocks enclosed within the sediments occur. Beneath the wedge crustal thickening can be observed, due to either accretionary underplating or crustal stacking. This could mean that here two phases of subduction took place or that the whole downgoing lithosphere is thrust-faulted.

Transient pore pressure evolution and the field of gas hydrate stability in growing accretionary wedges

N. Kukowski, T. Schillhorn (GEOMAR, U Kiel ,Wischhofstr.1-3, D-24148 Kiel, Germany, e-mail: nkukowski@geomar.de)

When deep sea sediments are accreted and subducted at convergent margins, large amounts of fluids are released due to tectonic dewatering as well as chemical reactions, which may cause the evolution of significant overpressuring and also affect the thermal field. Furthermore, changing p-T conditions change the stability field of gas hydrates.
Because of material transfer and plate convergence, the hydraulic processes within accretionary wedges are highly transient. Therefore, we developed a model concept combining transient finite element calculations for the fully coupled thermohydraulics with the self-similar growth of a wedge. The controlling physical and geometric parameters (e.g. slope angle, dip of the oceanic plate, rate of convergence, permeability tensor, porosity, thermal conductivity, basal heat flow, matrix heat production) may be chosen arbitrarily to match the characteristics of specific places.
Excess pore pressure begins to evolve near the deformation front and then over the whole wedge within several 10^4 years. Overpressuring in the subducting sediments needs more time to evolve than in the wedge. The boundary of gas hydrate stability can migrate some 10^1m within some 10^4 years in vertical direction mainly due to the transient hydraulics. This concept is applied to the Cascadian margin as a field example.

NUMERICAL MODELLING OF FOCUSSED FLUID FLOW IN THE CASCADIA ACCRETIONARY WEDGE

D. Mann, N. Kukowski (GEOMAR, Wischhofstr. 1-3, D-24148 Kiel, Germany, e-mail: dmann@geomar.de)

Fluid flow is supposed to influence significantly the dynamics in accretionary wedges. One of the most interesting questions is the role of focussed fluid flow along fracture zones compared with diffuse flow distributed over the whole wedge.
Based on seismic and borehole data (ODP Leg 146) from the Cascadia Accretionary Wedge we used the finite element method to model the thermal and hydraulic processes in a fault zone and its environment.
We tested a wide range of material parameters, boundary conditions and a more complex structure of the fault, and calculated temperature-, pressure- and fluid velocity fields.
The results show that fluid flow along fractures has a significant contribution to the dewatering of the wedge. The calculated flow velocities are several orders of magnitude faster than that of diffuse flow.
A transition zone between fault and rock matrix, even though it has only a slightly higher permeability than the matrix, supports the focussing effect of the fault zone and influences its fluid velocity. However it drops the pore pressure which could later lead to the closure of the fracture.

WIDE-ANGLE SEISMIC IMAGING OF A CONVERGENT CONTINENTAL MARGIN: ACCRETE

I.B. Morozov and S.B. Smithson (Dept. of Geology and Geophysics, University of Wyoming, Laramie, WY 82071-3006, USA)

L.S. Hollister, (Department of Geology, Princeton University, Princeton, NJ 08544, USA)

Seismic imaging of the continental margin of northern British Columbia during the '94 ACCRETE resulted in a wide-angle dataset of an outstanding volume and quality. Nearly 28,000 airgun shots at 50-150 m spacing were recorded by 60 3-component REFTEK stations, providing dense sampling of the crust and of the Moho discontinuity by P and S waves. Mantle refractions are observed at the offsets of 140-250 km. We present P- and S-wave velocity structures along the main line of the transect obtained using travel-time field refraction/reflection tomography and ray tracing techniques. The resulting model shows lateral velocity contrasts in the upper crust, approximately constant but above average lower crustal velocities, and Moho dipping towards the interior of North America. Several west-dipping prominent reflectors in the lower crust may be associated with late Miocene extensional mylonitic shear zones, or east vergent, late Cretaceous thrust shear zones.

TIEN-SHAN SOURCES DISTRIBUTION, DEEP STRUCTURE, DEFORMATIONS RESULTED FROM INDIA-EURASIA PLATE CONVERGENCE

E. Musienko , Z. Kalmetieva (Institute of Seismology, Asanbay 52/1, 720060, Bishkek, Kyrgyzstan)

There is phenomenon of intracontinental high seismicity the Tien-Shan existing as the result of total India-Eurasia plate convergence. Tien-Shan demonstrates most of the strong shallow crustal events along northern and southern tectonic boundaries, and around intermountain basins. The features of the deep structure in the Tien-Shan, intense deformations in upper crust and on the surface, distribution of hypo and epicenters have been analysed through following data: gravity anomalies Bouger; the focal mechanism solutions of large sized earthquakes; Moxo discontinuity position; types of the modern vertical tectonic motions; earthquake catalogue. Spatial distribution of hypocenters has clearly indicated sources location near or on boundaries of density inhomogeneities in the crust both vertical and lateral; simultaneous Moxo discontinuity immersion or breach of linear configuration have been observed; and contrast vertical tectonic motions took place on the surface. Statistical analysis of hypocenters distribution and of its links with local conditions shows that 70% of available events were held by the mentioned combined circumstances. The simplest explanation of this phenomenon may be superposition of regional compressive stress (N-S shortening across Tien-Shan reaches 12 +/- 2 mm/yr according GPS network data) and simultaneous contrast vertical straining motions along boundaries of tectonic structures oriented near perpendicular to stress direction (intensity range varies from +9.4 mm/yr for ranges to -7.5mm/yr for basins by geodetic data).

SUBDUCTION AND COMPLEX ACCRETION AT THE ACTIVE CONTINENTAL MARGIN OFF NORTH SULAWESI, CELEBES SEA

S. Neben, H. Beiersdorf, G. Delisle, J. Fritsch, K. Hinz, H.A. Roeser
all at: Federal Institute for Geosciences and Resources, Stilleweg 2, 30655 Hannover, Germany. E-mail: neben@sdac.hannover.bgr.de

The main targets of the international project GIGICS (**Co-operative German-Indonesian Geoscientific Investigations in the Celebes Sea**) were the investigation ofthe crust and internal structure of that region and the processes which shaped its active continental margins. Therefore a dense grid of over 3,000 km multichannel reflection seismic profiles together with over 6,000 km of magnetic, gravitmetric and bathymetric data were collected in the Celebes Sea during SONNE cruise SO98 in 1994. A special aim of the project was to image the internal architecture of the accretionary complex off north arm of Sulawesi Island in the southern part of the Celebes Sea.
The seismic data show two different accretionary units in this subduction zone. An approximately 25-30 km wide younger sedimentary wedge shows intense deformations by thrusting. Paleomagnetic data suggest that this wedge formed during the last 5 Ma. Landward of that wedge an older accretionary unit is present that shows a complex internal structure. We suggest the presence of oceanic crustal rocks obducted during the initial subduction process. This unit is overlain at its landward older portion by a sedimentary forearc basin having a 'thickness' of up to 2.5 s reflection time.

REFLECTION CHARACTERISTICS AND DISTRIBUTION OF BOTTOM SIMULATING REFLECTORS OFF NORTH SULAWESI, CELEBES SEA

S. Neben, K. Hinz, H. Beiersdorf, G. Delisle
all at: Federal Institute for Geosciences and Resources, Stilleweg 2, 30655 Hannover, Germany. E-mail: neben@sdac.hannover.bgr.de

Co-operative German-Indonesian Geoscientific Investigations in the Celebes Sea aiming at the crustal structure and the tectonic evolution of that region were performed during SONNE cruise SO98. The comprehensive data set includes - among others - over 3,000 km MCS profiles in combination with geological and geochemical sampling and heat flow measurements.
The seismic data of the southernmost profiles across the subduction zone off North Sulawesi show strong bottom simulating reflections (BSRs) and hence, the presence of gas hydrates in the lower and upper slopes of the accretionary wedge. The appearance and the reflection characteristics of the bottom simulating reflectors were revealed in detail and correlations between the presence of BSRs, the heat flow data and bottom water samples were achieved. Finally, the distribution of BSRs and the the depth below the ocean bottom were mapped.
The occurence of bottom simulating reflectors is limited to the central part of the North Sulawesi subduction zone. On the westernmost profile the seismograms show reflections on the lower slope of the accretionary wedge which are interpreted as sedimentary slumps. In these regions no or only very few and short BSRs are found, obviously as a result of those investigations.

INTERNAL CRUSTAL STRUCTURE OF THE NORTHERN CELEBES SEA, INDONESIA - JUVENILE OR STARVED SUBDUCTION ?

S. Neben, K. Hinz, J. Fritsch, H. Meyer
all at: Federal Institute for Geosciences and Resources, Stilleweg 2, 30655 Hannover, Germany. E-mail: neben@sdac.hannover.bgr.de

The main targets of the international project GIGICS (**Co-operative German-Indonesian Geoscientific Investigations in the Celebes Sea**) were to investigate the internal structure and the evolitionalary/tectonic history of the oceanic crust of the Celebes Sea. Within this scope SONNE cruise SO98 was conducted establishing a dense grid of geophysical and geological data.
The seismic data of the northern area of the Celebes Sea, south of the Sulu Archipelago, show internal crustal structures which indicate that the area was or is exposed to compressional forces.
The oceanic crust bends down when approaching the Sulu Arc from the southeast. The amount and angle of the deformation as well as the width of the area affected varies along the Sulu Archipelago. The biggest amount is found in the middle of the Sulu Arc. Here, the downbended crust shows the largest inclination, comparable to the angle of subduction under North Sulawesi. At both the western and the ea-stern ends of the Sulu Arc the depression or downbending of the oceanic basement is less pronounced. The deposits which build up a sedimentary basin at the toe of the Sulu Arc are deformed by thrust faults indicating a compressional stress regime.
Two possible interpretations for the evolution of the crustal structure of the northern Celebes Sea south of the Sulu Archipelago will be discussed.

TECTONIC STRUCTURE AND HEAT FLUX OF THE PACIFIC CONVERGENT MARGIN OF COSTA RICA

C.R. Ranero and R. von Huene (GEOMAR, Wischhofstraße 1-3, 24148 Kiel, Germany)
I. Pecher (Woods Hole Oceanogr. Inst. Woods Hole, MA 02543, USA)

Pre-stack depth migrated reflection profiles show a detailed image of the tectonic structure along the Pacific Margin offshore Costa Rica. Also, heat flux calculated along the lines showing a bottom simulating reflector (BSR) yields information on the thermal structure of the margin. Depth sections show that the margin has a small frontal accretionary prism, 5-15 km wide and 1-1.5 km thick. Landward, a wedge-shaped unit comprises the bulk of the continental margin. This unit has a rough top surface and gentle, landward-dipping reflections. Overlying slope sediment show folding in the lower strata. Most of the ocean basin sediment is subducted. The overall structure suggests that little accretion is occurring and the margin is probably eroded.
BSRs are widespread along the margin. Heat flux varies greatly, particularly at the trench and upper slope. In the NW, heat flux decreases steadily from the trench to the upper slope. In the SE, in the area where the Cocos Ridge (a hotspot trail) is being subducted, we found general higher values and a distinct positive anomaly at the front of the prism. We discuss the tectonic structure and heat flux pattern in the context of the kinematic setting of the area.

STRUCTURAL STYLE VARIATION ALONG THE SOUTHERNMOST CHILEAN SUBDUCTION COMPLEX

A. Polonia, G. Brancolini (OGS, P.O. Box 2011, 34016 Opicina, Trieste, Italy)
L. Torelli (Istituto di Geologia, University of Parma, Parma, Italy)

Seismic data collected along the southernmost Chilean continental margin (54=B0S-57=B0S) by R/V OGS-EXPLORA, reveal the complex structural setting of this area. Antarctic plate sediments scraped off from the descending plate are piled up in a classical andean type subduction complex which is accreted against an hard continental backstop. Over the backstop a stress-free zone is present and a forearc basin, approximately 2 km thick and 15 km wide, can grow largely undeformed. The analysis of the multichannel seismic profiles reveals that structural style (width of the accretionary complex, taper angle, proto-thrust domain, structural vergence and deformation in the forearc basin) varies along the margin. Large tapers are peculiar of the southernmost area and they are related to a narrower wedge and only to seaward vergent structures. Low tapers are peculiar of the northern and central region where brittle and ductile deformation at the toe of the accretionary complex is spread over a wider area, both landward and seaward vergent thrust faults are present. Structural differences are related to variations in the depth of the d=E9collement level, to the width of the terraced continental slope and to the presence of overpressured fluids. In March 1997 a new cruise is scheduled to investigate the triple junction between Antarctic, Scotia and South America plates around 52=B0S and the new survey will verify the existence of brittle rotating crustal blocks bounded by the offshore activity of the strike slip faults, well described on land.

DEEP STRUCTURE OF THE SOUTH CASPIAN BASIN

M.V. Rodkin (Geophysical Center, Molodezhnaya 3, 117296 Moscow, Russia, rodkin@wdcb.rssi.ru), A.N.Yakobson (OIFZ, B. Gruzinskaia 10, Moscow)

Seismic structure of the upper lithosphere of the South Caspian Basin revealed from the high resolution surface waves study was analyzed in complex with data on the crustal heat flow regime, effective conductivity of the sedimentary cover and earthquake foci localization. A few graben-like structures were detected in the deep part of the very thick sedimentary layer. Our data testify also for the existence in the region under study of the thick low Vs velocity layer separated from the sedimentary cover by the layer with Vs velocities typical of the lower crust and of the upper mantle. Thickness and Vs values of the low velocity (mantle?) layer and of the sedimentary cover show strict correlation with the effective conductivity of the sedimentary cover. This correlation could be connected with the presence of the free fluid throughout the deep strata of the sedimentary cover and in the (mantle?) low velocity layer. Geodynamic aspects of the problem and possible fluid concentrations needed to cause the observed Vs and conductivity anomalies are modeled and discussed.

IMPROVED OFF-SHORE HYPOCENTER LOCATION IN NICARAGUA

E. Rüttener, E. Kissling and W. Rasa (Institute of Geophysics, ETH-Hönggerberg, CH-8093 Zürich, Switzerland; erik@seismo.ifg.ethz.ch)
W. Strauch (Instituto Nicaragüense de Estudios Territoriales, Apdo. Postal 2110, Managua, Nicaragua)

The high seismic activity in Nicaragua is concentrated in the subducting Nazca plate and in the crustal block along the volcanic belt. Local off-shore earthquakes play a significant role in the tsumani hazard of the Nicaraguan coast. These events are usually badly located due to their location outside the seismograph network. Data collected in a 7-months field experiment are used to derive a minimum 1-D velocity model, which can be tuned to the location of off-shore events.
A 10-day extension of the network with 10 OBS distributed above the seismogenic off-shore region allows the calibration and verification of the velocity model. It can be shown that the minimum 1D-model significantly improves hypocenter locations of off-shore earthquakes in Nicaragua.

COMPARISON OF THE INFLUENCE OF CRUSTAL STRUCTURE DURING THE SUBDUCTION AT THE MIDDLE AMERICA TRENCH AT THE COSTA RICA PACIFIC COAST FROM WIDE- ANGLE SEISMIC MODELLING

A. U. Stavenhagen and E. R. Flueh (GEOMAR, Wischhofstr. 1- 3, 24148 Kiel, FRG)
G. L. Christeson and K. D. McIntosh (UTIG, 8701 North MoPac Expressway, 78759- 8397 Austin, Texas, USA)
H. Goedde, A. Schulze and J. Mechi (GFZ- Potsdam, Telegraphenberg 17a, 14473 Potsdam, FRG)

In 1995 the TICOSECT project started with an expedition to explore the subduction zones at the Middle America Trench (MAT) off Costa Rica. In three combined on- and offshore experiments, recordings from OBS, OBH and land stations of the shooting of the R. V. Maurice Ewing's 140 litre airgun array could be made to offsets of over 180 km. The aim of this project was to study the influence of different oceanic crustal plate segments of the subducted Cocos plate and their behavior in subduction. Two of the profiles were completed onshore across the Middle America Isthmus with explosive sources and land recordings during the 1996 COTCOR project. The presen-tation comprises three wide- angle seismic models of profiles that are located: 1. Transect beginning at the MAT, crossing northern Nicoya and extending to the Nicaraguan border with a total length of over 200 km. Here a smooth oceanic crustal segment is subducting. 2. At the southwestern edge of the Peninsula Nicoya and the Gulf of Nicoya, where a seamount dominated segment is subducting. A 120 km onshore-off-shore line is presented. 3. A 230 km long profile near the Osa peninsula, containing the second transect from the southern part of Costa Rica. This line starts 20 km west-wards the MAT and extends over the shelf area and the Middle America Isthmus to the atlantic coast of Costa Rica. In this segment, the rough Cocos Ridge area is subducting.

THE DEEP STRUCTURE OF THE LITHOSPHERE BENEATH THE SEISMIC REGIONS IN THE TRANSITION ZONE FROM EURASIAN CONTINENT TO THE PACIFIC OCEAN.

A.G.Rodnikov, Geophysical Center, Russian Academy of Sciences, Molodezhnaya,3, Moscow, 117296, Russia

Research was carried out along three geotraverses made on the base of complex interpretation of geological and geophysical data. The first geotraverse across the structures of the Sikhote Alin, Japan Sea, Honshu Island and Northwest Pacific Basin was prepared jointly with Japanese scientists. The second geotraverse across the North China Plain, East China Sea, Philippine Sea and Mariana Island Arc was carried out jointly with Chinese and Japanese specialists. The third geotraverse being under preparation now runs across the Sikhote Alin, Sakhalin, Sea of Okhotsk, Kuril Island Arc and Pacific.
The sleep dipping Benioff zone of deep earthquakes, with is almost vertical at the Mariana island arc, extends to a depth of about 600 km.
The major peculiarity of the deep structure of the lithoshere is the presence in the upper mantle of the asthenospheric lens of the processes that determine the development of geological structures. The islad arcs are located above the junction of the two flows in the asthenosphere: the heat flow from beneath the continent and cold flow of the Pacific.

RAPID VARIATION IN SUBDUCTION ACCRETION VS. NON-ACCRETION OFF COSTA RICA: ODP LEG 170 RESULTS

E.A. Silver (Earth Science Dept. and Inst. of Tectonics, University of California, Santa Cruz, CA 95064)
G. Kimura (Dept. of Earth Sciences, Osaka Prefecture University, College of Integrated Arts and Sciences, 1-1, Gakuen-cho, Sakai-shi 593, Japan)
P. Blum (Ocean Drilling Program, TAMU, College Station, TX 77845-9547)
and the Leg 170 Scientfic Party

Both accretion and non-accretion are documented near the front of the Costa Rica margin. Site 1043, 400 m from the toe of the wedge, shows about 90% of the incoming strata bypassing the toe (also seen on seismic records), and the wedge above is composed of offscraped material. But at Site 1040, 1.6 km from the toe, 99% of the sedimentary section is subducted, and the wedge above resembles the upslope apron rather than the incoming strata. Both sites show that some material in the deformed wedge is composed of intermixed debris flows and sedimentary breccias. At Site 1040, the underthrust hemipelagic section is flattened to 67% of original, whereas the underlying pelagic ooze is flattened to 80%, implying considerable dewatering of the underthrust strata. Geochemistry suggests that the base of the the trench sequence has seawater communication, possibly expanining the anomalously low heat flow on both the lower and upper plates. Site 1042, 7 km from the toe, encountered middle Miocene carbonate-cemented breccia containing clasts of sandstone, red chert and ultramafic rock, with likely affinities to onland geology. Though underplating exists, overall accretion appears limited.

MODELING OF FLUID TRANSPORT IN SUBDUCTION ZONES

E.I. Suetnova(United Institute of the Physics of the Earth, RAS, B.Gruzinskaya 10,Moscow 123810,Russia)

Studying of fluid movement in subduction zones is necessary for understanding the processes at slab-mantle interface, heat transfer, rheology and melting of mantle wedge. The source of volatiles in a subducting slab is the hydrothermally altered upper layer of the oceanic plate. As a slab descends and heats up, decarbonation and dehydration reactions cause alteration minerals to release volatiles. Thermomechanical model of metamorphic fluid movement inside subducting slab is suggested.The system of governing equations describes thermal regime of dehydratation of downgoing slab, upward movement of metamorphic fluid and compaction of the slab media. The model is applyed to Kuril- Kamchatka subduction zone.Velocity of metamorphic fluid movement is determined and the transition to hydrofracturing is investigated.The results are applyed to interpretation of the variations of depth of seismicity along Kuril-Kamchatka subduction zone.

Sergei A. Ushakov[1] & Lidia A. Ushakova [1]

Accretionary nature of Sakhalin island and seismic catastrophe on the May 27 1995

[1] Lomonosov Moscow State University, Earth Sciences Museum and Geograpy Department Moscow, Russia

The reasons of seismic catastrophe upon the northern Sakhalin island on the May 1995 are examined. Geomorphological and geophysical data analysis allows to propose that the Sikhote Alin mountains are forming as a result of continental lithosphere contraction and the Okhotsk Sea oceanic lithosphere subduction under them with the small linear velocity (V < 1cm/year). According such interpretation of the Sikhote Alin mountains geodynamic origin it is naturally to suppose that the Sakhalin island is the summit of accrertionary prism developing in the slow subduction process of the Okhotsk Sea lithosphere under Sikhote Alin mountains. This prism is formed predominantly from sedimentary rocks with the ophiolite spots and goes on to form at present being compressed and sheared.The conclusion is done that similar situation (slow subduction and/or collision) takes place in the north -easterrn China and eastern Korean peninsula transitional zone.

FROM COCOS TO CARIBBEAN PLATE - SEISMIC INVESTIGATIONS OFFSHORE NICARAGUA

Ch. H. E. Walther, E. R. Flueh, C. Ranero and R. von Huene (GEOMAR, Research Center for Marine Geosciences, D-24148 Kiel, Wischhofstr. 1-3, Germany)

In early 1996 seismic wide angle measurements were carried out offshore Nicaragua during leg SO 107 of the German RV SONNE using airguns as source and ocean bottom hydrophones (OBH) as well as landstations for recording.

A 200 km long dipline profile extended from the Cocos Plate across the Middle American Trench and the continental margin of the Caribbean Plate close to the Nicaraguan coast. This dipline was choosen coincident with a seismic reflection profile (10 s record length) recorded by the University of Texas in 1977 and reprocessed at GEOMAR. Two 100 km long strike profiles were situated 40 and 70 km landward from the trench. OBH spacing was 10 - 25 km. The major objective is to reveal the transitional structure between the oceanic crust of the Cocos Plate and the continental crust of the Chortis Block as part of the Caribbean Plate.

First results show a strongly faulted oceanic plate with a 0.5-1 km thick pelagic sediment cover. The oceanic crust shows a clear division into layer 2 and 3 with almost 7 km/s at the base of the crust. Near the trench axis the Moho reaches 12 km depth and dips about 5 degrees. Across the lower and steep middle slope the seismic data show only a thin sedimentary cover. Sediments on the upper slope and shelf thicken towards the center of the Sandino Basin to almost 4 km (3 s TWT) with velocities around 2.5 km/s. Beneath the basin high velocities from 5-6.5 km/s indicate the presence of ophiolitic crust in the continental margin wedge.

SE29/NP1.1 Scaling, multifractals and nonlinearity in solid Earth geophysics

Convener: Schmittbuhl, J.
Co-Conveners: Bak, P.; Herrmann, H.J.; Turcotte, D.L.

CRUSTAL STRUCTURE OF THE CONTINENTAL MARGIN OFFSHORE-ONSHORE VALPARAISO

N. Vidal, C. Ranero, E. Flueh, A. Hojka and R. von Huene (GEOMAR, Wischhofstrasse 1-3, Kiel, D24148 Germany)
J.J. Danobeitia (Inst. of Earth Sciences, CSIC, Solé i Sabarís s/n, 08028 Barcelona, Spain)
D. Córdoba (Dept. Geophysics, UCM, 28040 Madrid, Spain)
K. Hinz (BGR, Stilleweg 2, 30655 Hannover, Germany)

During 1995 seismic measurements were collected at the latitude of Valparaiso (Chile) within the multidisciplinary CONDOR (Chilean Offshore Natural Disaster and Ocean Enviromental Research) programme. In this area a fundamental change in the configuration of the Benioff zone, volcanic arc activity, and the structure of the continental margin occurs opposite the subducting Juan Fernandez ridge. The experiments include a first seismic profile, located away from the influence of the subducting ridge, crossing the margin where thick trench sediment and an accreationary wedge near the trench is observed. A second profile located to the north, runs from Juan Fernandez ridge to the coast. The crustal velocity models obtained for the two profiles together with the coincident seismic reflection data show that the continenal crust extends to the middle-lower slope boundary. The oceanic plate is rather similar, but appears to be slightly more inclined along the northern profile. Upper plate tectonics related to the subduction of the ridge explain structural differences observed between both areas.

PARAMETRIC REZONANCE OF A LIQUID DROPLET OSCILLATION IN A FILAMENT CAPILLARY OF A POROUS MEDIUM.

Averbach V.S.,Zaslavsky Yu.M.(Institute of Applied Physics Russian Academy of Sciences, 46, Ul'anov str., 603600, N.Novgorod, Russia)

In our report we have briefly analysed the physical process of solitary water dropplet parametric oscillation in filament capillary of porous geomaterial under incedent P seismic wave. The estimation is received of nonlinear parametric oscillations and the conditions of optimal excitation is clarified. The problem is interesting in a seismic action to increase of a debite productivity of boreholes filled with an oil and gas.

INTERFACE EFFECTS AND INTERMITTENCY IN BLOCK SLIDINGS

V.P. Brito (Departamento de Física, UFPI, 64049-550, Teresina, PI, Brazil)
M.A.F. Gomes (Departamento de Física, UFPE, 50670-901, Recife, PE, Brazil)

It is shown that the measured length distribution of slidings of solid blocks on an incline in response to small perturbations obeys nontrivial scaling laws which depends on the *dimensionality* of the interface but are to a large extent independent of material and angle of inclination. These scaling laws are reminiscent of the Gutenberg-Richter law and are more sharply defined than the analogous distributions obtained in somewhat related experiments involving avalanches in sandpiles and liquids performed in the last few years by a number of authors. Furthermore, the average time interval τ between these block slidings or "blockquakes" scales with the length L of the blocks as $\tau \sim L^{\alpha}$, $\alpha = 0.56 \pm 0.02$, in agreement with the law governing the average time between earthquakes on faults with characteristic size L.

ANALYSIS OF THE TEMPORAL OCCURRENCE OF SEISMICITY AT DECEPTION ISLAND (ANTARCTICA). A NONLINEAR APPROACH

Antoni M. Correig(1), Merce Urquizu(1), Josep Vila(1) and Joan Marti(3)
1 Departament d'Astronomia i Meteorologia, Universitat de Barcelona. Marti Franques 1. E-08028 Barcelona. Spain.
2 Institut de Ciencies de la Terra "Jaume Almera", CSIC. Lluis Sole Sabaris s/n. E-08028 Barcelona. Spain.

Deception Island is characterized by small magnitude local events with constant energy flux and very low stress drop. To obtain information about its origin, an interevent time series of 546 events, corresponding to an observational period of two month, has been analyzed. From a statistical point of view, data satisfies a Weibull distribution and presents clustering. A rescaled range analysis reveals that data are not independent, {\it i.e.} have memory, and the correlation dimension saturates at 2.2; as a consequence, the system can be modeled as a non-linear iterative equation with three degrees of freedom that presents chaotic behavior. Taking into account that the average interevent time is of the order of 130 minutes, too short to be due to only tectonic activity, the above results indicate that some other mechanism may coexist with the regional tectonic one. According to several geological and geophysical observations we suggest that most of the local events may be originated by pressure waves generated by a sudden change of phase, of sea and fresh water infiltrated into the main fractures and faults and also from shallow and confined water-saturated layers.

UNIVERSAL MULTIFRACTAL ANALYSIS OF SURFASES OBTAINED BY BREAKAGE OF BASALT SPECIMENS

A.V.Chygyrynsky (Department of Material's Resistance, Ukrainian Agricultural University, Kiev, Ukraine)

A series of laboratory measurements of classical parameters considered by material's resistance theory, such as loss of strength and breakage point, of basalt specimens in bending and in tension were carried out in Department of Material's Resistance (Ukrainian Agricultural University). The examination of different surfaces obtained by breakage of test specimens were performed with the help of universal multifractals (Schertzer, Lovejoy, 1987), determining their Levy index (α) of multifractality and critical order of first order phase transition q_D which leads to the appearance of non-classical Self Organized Criticality. We compare obtained result with those are presented in (Shmittbuhl et al., 1995).

EARTHQUAKE STATISTICS IN SIMPLE MODELS OF HETEROGENEOUS FAULT ZONES

K. A. Dahmen, D. S. Fisher and D. Ertas (Department of Physics, Harvard University, Cambridge, MA 02138, USA)
Y. Ben-Zion (Department of Earth Sciences, Univ. of Southern CA, Los Angeles, CA, 90089-0740, USA)

Observations have shown that earthquakes exhibit apparently universal scaling of the rupture size distributions and related quantities. We study simple models for ruptures along a heterogeneous earthquake fault zone with quasistatic stress transfer, in particular focusing on the interplay between the roles of disorder and long range elastic interactions. It is found that there is a critical point in a class of such models whose properties might underly the observed power law scaling of real earthquake statistics. We examine the effects of both the amount of disorder in the fault properties and finite fault size effects, on earthquake sequences and the distribution of event magnitudes. The studies employ mean-field theory and other analytic methods as well as three-dimensional simulations. Some effects of dynamic stress transfer via seismic waves have also been explored.

QUASI-STATIC CRACK PROPAGATION IN HETEROGENEOUS MEDIA

Deniz Ertas, Sharad Ramanathan and Daniel S. Fisher (Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138, USA)

The dynamics of a single crack moving through a heterogeneous medium is studied in the quasi-static approximation. Equations of motion for the crack front are formulated and the resulting scaling behaviour analyzed. In a model scalar system and for mode III (tearing) cracks, the crack surface is found to be self affine with a roughness exponent of $\zeta = 1/2$. However, in the usual experimental case of mode I (tensile) cracks, local mode preference causes the crack surface to be only logarithmically rough, quite unlike those seen in experiments. The effects of residual stresses are considered and found, potentially, to lead to increased crack surface roughness. Nevertheless, it appears likely that elastic wave propagation effects may be needed to explain the very rough crack surfaces observed experimentally.

MULTI-SCALE IMAGE ANALYSIS : THE NORMALISED OPTIMISED ANISOTROPIC WAVELET COEFFICIENT (NOAWC) METHOD.

P. Gaillot, J. Darrozes, G. Ouillon, M. de Saint Blanquat, J.L. Bouchez (UMR 5563 CNRS - 38 rue des 36 ponts F-31400 Toulouse)

Investigation of complex spatial organisations, such as rock fabric, necessitates recognition and understanding of a number of physical processes acting simultaneously at different scales. Finding out the part taken by each spatial organisation, according to its characteristic scale, is an effective way to analyse such systems.
This approach can be automatically performed by the Normalised Optimised Anisotropic Wavelet Coefficient method (NOAWC) which allows to decipher signals where information of different scales are combined.
Multi-scale rock fabric analysis using the NOAWC method leads to recognise and quantify (size, shape anisotropy, orientation and location) the different levels of mineral organisation : (i) the mineral, (ii) the spatial organisation of minerals or texture, (iii) the spatial variation of texture leading to identification of connex entities as, for example, clusters of grains, and finally (iv) the spatial distribution of the connex entities or structure, such as alignments of clusters.

DYNAMICS OF SOLITARY RELAXATIONS IN AN EXPERIMENTAL BURRIDGE-KNOPOFF LIKE SYSTEM

J. Galeano (EUITAgricolas, UPM, Ciudad Universitaria, Madrid Spain)
P. Espanol and M.A. Rubio (Dpto. Fisica Fundamental, UNED, Apdo Correos 60141, 28080 Madrid, Spain)

We report on experiments on the dynamical behavior in a model system for earthquakes and stick-slip dynamics. In the experiments, shear is imposed on a transparent gel in between two coaxial circular cylinders [1]. The stress relaxations are investigated locally by means of photoelastic techniques and several dynamical regimes are found.
We will focus on the propagating relaxations (PR) regime where one or more localized regions slip simultaneously. The velocities of the PR's are 100 to 1000 times larger than the pulling speed. Moreover, their velocities are proportional to the pulling speed and the rigidity of the gel and inversely proportional to the number of PR's present in the system.
We will present numerical simulations of a Burridge-Knopoff model with Coulomb friction that display stable subsonic PR's exhibiting similar behavior. In the continuum limit subsonic propagations are forbidden but stable subsonic PR's involving only few blocks can be constructed. This suggests that the experiment has a *discrete-like* behavior and we will provide some hints on the physical origin of this effect.
[1] M.A. Rubio and J. Galeano, Phys. Rev. E, **50**, 1000 (1994)

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Investigation of complex spatial organisations, such as rock fabric, necessitates recognition and understanding of a number of physical processes acting simultaneously at different scales. Finding out the part taken by each spatial organisation, according to its characteristic scale, is an effective way to analyse such systems.
This approach can be automatically performed by the Normalised Optimised Anisotropic Wavelet Coefficient method (NOAWC) which allows to decipher signals where information of different scales are combined.
Multi-scale rock fabric analysis using the NOAWC method leads to recognise and quantify (size, shape anisotropy, orientation and location) the different levels of mineral organisation : (i) the mineral, (ii) the spatial organisation of minerals or texture, (iii) the spatial variation of texture leading to identification of connex entities as, for example, clusters of grains, and finally (iv) the spatial distribution of the connex entities or structure, such as alignments of clusters.

FRACTAL DIMENSION OF MAGNETIC SIGNALS:COMPUTING ALGORITHMS

F.Giordano* I.Ortosecco** L. Tramontana*

*Istituto Universitario Navale -Napoli- Italy
**Dipartimento di Scienze Fisiche Univ. Federico II Napoli

ABSTRACT
In previous works we studied fractal character of marine measuring networks, in which total Earth Magnetic Field (E.M.F.) is sampled with a moving ship, in other words, without fixed position (kinematic GPS). We computed , by Grassberger and Procaccia Method, the value of Fractal Dimension (FD) of several measuring networks giving for all of them values near 1.80,it seems to be a typical value. In the first part of this work, we introduce four algorithms related to corresponding methods for fractal dimension evaluation. In fact, computing method for F. D. evaluation depends by some properties (self-similarity, self-affinity,etc.)of points distribution. The algorithms were tested on fractal synthetic planar curves. In the second part we evaluete fractal properties of

FRACTAL GEOMETRY AND EARTHQUAKES STATISTICS

R. Hallgass (Dipartimento di Fisica, Università dell'Aquila)
Vittorio Loreto (P.M.M.H. Ecole de Physique et Chimie Industrielles, 10, rue Vauquelin, 75231 Paris CEDEX 05 France)
O. Mazzella (Dipartimento di Fisica, Università di Como, Como, Italy)
L. Pietronero (Dipartimento di Fisica, Università di Roma 'La Sapienza', P.le A.Moro 2 I-00185 Roma, Italy, and INFM, unità di Roma1)

We present a Self-affine Asperity Model (SAM) for the seismicity that mimics the fault friction by means of two fractional Brownian profiles (fBm) that slide one over the other. An earthquake occurs when there is an overlap of the two profiles representing the two fault faces and its energy is assumed proportional to the overlap surface.
The SAM exhibits the Gutenberg-Richter law with an exponent β related to the roughness index of the profiles. Apart from being analytically treatable, the model exhibits a non-trivial clustering in the spatio-temporal distribution of epicenters that strongly resembles the experimentally observed one. A generalized and more realistic version of the model exhibits the Omori scaling for the distribution of the aftershocks.
The SAM lies in a different perspective with respect to usual models for seismicity. In this case, in fact, the critical behaviour is not Self-Organized but stems from the fractal geometry of the faults, which, on its turn, is supposed to to arise as a consequence of geological processes on very long time scales with respect to the seismic dynamics. The explicit introduction of the fault geometry, as an active element of this complex phenomenology, represents the real novelty of our approach.

CHAOS IN GEODYNAMO AND PRECISION OF REAL PALEOMAGNETIC DATA.

Pavel Jasonov (Faculty of Physics, Kazan University, Kazan, 420008, Russia).

The time series of geomagnetic field reversals (GFR) are very irregular, but number of well dated reversals in Earth's history amount to not more than 300. This is too few for correct determination of statistical properties of the reversal process, and it is only possible to determine intervals where these parameters change. Time series generated by Rikitake disc dynamo models have been calculated for comparation with real geomagnetic field reversals (GFR) time series. There are some important differences between the real and model data, such as some error in the time scales of the real data. A number of model time series have been constructed taking into account these problems. The limits of the change in statistical properties of the model data (types and parameters of distribution, correlation dimension) have been obtained. Correlation dimension strongly depends upon precision of determination of reversal moments in time series, generated by dynamo model. This fact shows that behavior of geomagnetic field could be described by the system with low correlation dimension, such as disc dynamo model.

FINITE-SIZE SCALING OF CONDUCTIVITY IN FRACTAL GETEROGENEOUS MEDIUM

S. S. Krylov and N. Y. Bobrov (Institute of Physics, St. Petersburg State University, St. Petersburg, Russia 198904)

When the concentration of high-conductive component in heterogeneous medium approaches to critical value (percolation threshold), such a medium becomes a geometric fractal. Within fractal area average electrical characteristics (i.e. conductivity, dielectric constant, relaxation time) obey finite-size scaling lows. This effect can take place both for microscale (the case of porosity) and for macroscale (geological features). In the last case one can to investigate the scaling by different electromagnetic arrays used in electrical prospecting. There have been carried out a special experiments in the permafrost region over the layer of frozen saline clay possessing high ice-content. The investigations revealed the fractal structure of frozen rocks, which contain segregated ice veins and sedges. This can be a result of self-organized criticality state, connected with temperature phase transition in permafrost. The results of investigations allow to evaluate scaling exponent and choose the model of frozen rock structure.

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CONNECTION OF FRACTAL PROPERTIES AND SCALING OF THE MAGNETIC FIELD REVERSALS WITH THE REGIME CHANGE OF THE EARTH'S CORE CONVECTION

V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3, Novosibirsk 630090, Russia)

It is shown by us that the discovered earlier fractal properties and the scaling of the Earth's magnetic field reversals can be explained by the convection regime change in the outer core. The model suggested by us is based on the following: 1)the analysis of the splitting functions for 11S4 modes shows that in the outer core there are 12 convected cells of the tesseral harmonic T3/4 type; 2)it is suggested that the radius of the Earth's outer core did not change during the evolution, whereas the radius of the inner core has decreased; 3)with increasing the outer core thickness, number of the convecting cells formed in it was always decreasing; 4)the Earth's magnetic field changed its polarity, when the convection regime has changed, and its polarity did not change, when the convection was steady; 5)the convecting cells have the same fractal structure and they belong to the same versatility class. The calculated durations of the steady convection and the periods of changing its structure were compared with the periods of the Earth's magnetic field reversals. Their large community gives grounds to consider that this model is identical to the nature of the Earth's magnetic fiekd polarity change.

SELF-ORGANIZATION OF ENSEMBLE OF THE CRACKS EMITING THE SOUND

V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3, Novosibirsk 630090, Russia)

This paper proposes the model of the self-organization of cracks arising in the rock (granite) under a load. This model is based on using the presumed effect of acoustic wave interaction between the cracks being formed. This model uses some solutions of Fokker-Planck's equation. In this paper the results of laboratory experiments are explained in which such phenomena were found as the spontaneous increase of intensity of acoustic emission, its the spatial and temporal clastering and the formation of the fractal structure under the constant and smoothly varying load on the rocks samples. On the basis of this model, the attempt is made to elucidate the earthquake nature.

SCALING LAWS AND NON-LINEARITY IN GEOELECTRICAL PRECURSORY SIGNALS AND IN SEISMICITY ON SOUTHERN APENNINE CHAIN (ITALY)

V. Cuomo, V. Lapenna and V. Telesca (Ist. di Metodologie Avanzate di Analisi Ambientale, Area della Ricerca del CNR, 85050 Tito (PZ), Italy)
M. Macchiato (Dip di Scienze Fisiche, Università Federico II, Naples, Italy)
C. Serio (Dip. di Ingegneria e Fisica dell'Ambiente, Università della Basilicata, Potenza, Italy)

In this work we propose the self-organized criticality as a powerful tool to describe the complicate correlation between electrical precursory phenomena and seismicity in a selected area of the Southern Apennine chain. The appearance of self organized criticality is signed by spatial and temporal scaling laws in the precursory phenomena of electrical nature and in seismicity patterns. The space and time dynamics of the electrical signals is characterized by rich scaling properties that are typical of a wide class of fractional Brownian processes. Furthermore flicker noises are detected from the analysis of earthquake sequences; and, at the spatial scale, a self-similar structure in the epicentre aggregate is determined by the estimation of its fractal dimension. A correlation between the main dynamic features of the earthquake sequences and the local complexity of the seismotectonic environment is carried out. Our findings bring us insight the inner dynamics of the geophysical process under study: an estimate of the number of degrees of freedom of the dynamical system governing the generation of the electrical precursory phenomena is obtained. All the possible implications with the earthquake prediction problem are discussed.

ANALYSIS OF KTB LOG DATA: MAINLY $\frac{1}{f}$-NOISE IN CRUSTAL PROPERTIES

Leonardi, S. and Kümpel, H.-J. (Geological Institute - Applied Geophysics, Nussallee 8, D-53115 Bonn, Germany)

Small scale variations of geophysical borehole data reflect the geological inhomogeneities in the Earth's crust, i.e. its petrologic-mineralogic and structural organization, and bear meaningful information of past dynamical processes and evolution. In this work geophysical log data from the pilot hole (4000 m deep) and the main hole (9101 m deep) of the German Continental Deep Drilling Program (KTB) were analyzed for their statistical properties. The diversity of the log data (density, porosity, electric resistivity, seismic velocity, magnetic susceptibility and γ-ray) as well as their high resolution (6 inches sampling rate, i.e. 72,000 to 84,000 values per parameter) stand for a high significance of the results. Spectral and rescaled range analyses were applied to each data series. The results show that the spectral exponents b fall in the interval $-1.5 < b < -0.5$ and the Hurst exponents H range between 0.6 and 0.8. The best stochastic model expressing the small crustal heterogeneities is thus given by $\frac{1}{f}$-noise, with scaling behaviour from metres to thousands of metres. Further studies demonstrate that the statistical properties of the physical parameters do not change significantly with depth. $\frac{1}{f}$-noise and the related fractal character hint at a possible self-organized criticality in the dynamics of the Earth's crust.

SELF-ORGANIZED CRITICALITY. PARADIGM AND DESCRIPTION.

G.G.Malinetskii and A.V.Podlazov (Keldysh Institute of Applied Mathematics, Miusskaja pl. 4, 125047, Moscow, Russia)

Dynamics of many complex systems demonstrates power-law probability distributions. This phenomenon is regarded as self-organized criticality. Earthquakes gives us an example of SOC in the form of Gutenberg-Richter relation between quantity of earthquakes and theirs energy $N(E) \propto E^{-\alpha}$. Analysis of SOC from the point of view of branching processes theory is performed. Any branching process with independent particles can be described by universal law of "minus three seconds" $p(x) \propto x^{-3/2} e^{-\beta x}$. For branching processes with an interaction simulation gives a formula $p(x) \propto x^{-\alpha} e^{-\beta x}$, where α varies from 0 to 3/2 while interaction strength being changed. This enables one to observe a transition from the critical to non-critical behavior. So the criticality is a quantitative phenomenon and needs of a numerical measure. A mean value gives no information about big events and often could not be found from observations. Parameters of distribution have also a lot of shortcomings. We propose a new convenient statistical characteristic $\mathrm{Sc}x = \overline{x^2}/\overline{x}$ named scale. It determines the size of significant events occurring in system. Presence of two characteristic sizes (scale and average) is a fingerprint of criticality and their ratio represents its measure. SOC-models with open boundary conditions are quite difficult for studying. So we introduce a new closed model. It combines essential lucidity with opportunity to look after the whole spectrum of the properties of self-organized criticality both numerically and analytically.

DYNAMICALLY ACCESSIBLE OPTIMA IN NATURAL FRACTAL PATTERNS

M. Marani (Istituto di Idraulica, Università di Padova, I-35131 Padova, Italy)
A. Maritan (ISAS, I-34014 Grignano di Trieste, Italy)
I. Rodriguez-Iturbe (Texas A & M University, College Station, TX 77843, U.S.A.)
A. Rinaldo (Istituto di Idraulica, Università di Padova, I-35131 Padova, Italy)

Nonlinear self-organized processes have been suggested to be at work in the shap ing of natural landforms and to be responsible for the recurrent features observ ed in river networks. In particular it has been observed that these systems evol ve towards stab le minima of total energy dissipation. This is expressed in the concept of feasi ble optimality, which refers to the fact that the stationary states, and their f ractal and statistical characters, accessible to open, dissipative systems with many degrees of freedom are critically determined by their boundary conditions.
We study an example of such a system, made up of N metal balls free to move w ithin a medium of low electrical conductivity where charges are injected from ou tside. When grounded, the system self-organizes into aggregates which have been observed experimentally and possess scaling features. An exact variational principle of global nature is defined for the underlying Poisson problem and stable stationary states are at a minimum of total energy dissipation and total potential energy. Our numerical simulations are consistent with observatio ns and we find a finite-size scaling law that correctly captures the fractal cha racters of the observed structure.

USING FRACTAL AND EUCLIDEAN PORE DISTRIBUTIONS FOR MODELLING COMPRESSIBILITY IN POROUS ROCKS

J.S. Mendoza (Dept. Earth Sciences. Simon Bolivar University, Valle de Sartenejas, Edo. Miranda. Venezuela)

In this study we present a topological scheme for the pore space that can be used to explain the observed changes in porosity and the compressibility in porous rocks. In the model, porosity and the compressibility are computed by a boundary elements technique. Only a few pore shapes are considered, because we are interested in identifying which geometries are responsible for the main trend observed in the compressibility and the porosity, rather than fitting the data with a high degree of precision. Also, a forward model is used to simulate the changes in porosity and the compressibility and therefore the process becomes unmanageable when the number of shapes increases. We found that certain proportion of euclidean and fractal pores can account for the observed changes. The euclidean pores are used to describe the large amount of porosity, while the fractal shapes account for the large changes in the compressibility. On this way, we have constructed a model for the pore space that can serve as a starting point to compute other petrophysical parameters in porous rocks.

FRACTAL AND MULTIFRACTAL ANALYSIS OF THE MIXING IN MANTLE CONVECTION

L. Pachepsky (Dept. of Geology and Geophysics, Minnesota Supersomputer Institute Univ. Minnesota, Minneapolis, MN 55415-1227, USA)
Yu. Yu. Podladchikov (Geologisches Institut, ETH-Zurich, Sooneggstr. 5, CH 8092 Zurich, Switzerland)
D. A. Yuen (Dept. of Geology and Geophysics, Minnesota Supersomputer Institute Univ. Minnesota, Minneapolis, MN 55415-1227, USA)

Fractal and multifractal analysis was performed on a data set of convective mixing for Newtonian and Non-Newtonian rheologies. Two data sets were analyzed, the images of the passive scalar field and of the passive marker-chains. The scalar field variable represented the vertical position of fluid particles at t=0, the marker-chain corresponded to the shape of the initially horizontal line of particles at a fixed depth at t=0. Box counting technique was employed to determine the temporal evolution of the fractal dimension D for a range of scales and of the multifractal spectra D(q) and f(a). As a result, the subranges where the images of mixing exhibit fractal and multifractal properties were determined.

NUMERICAL SIMULATION OF BLOCK-STRUCTURE DYNAMICS: THE MODEL WITH 3D MOVEMENTS OF BLOCKS

L. Melnikova and V. Rozenberg (Institute of Mathematics and Mechanics, Ekaterinburg 620219, Russia)
A. Soloviev (International Institute for Earthquake Prediction Theory and Mathematical Geophysics, Moscow 113556, Russia)

The block model of lithosphere dynamics with 3D movements of blocks is presented. A seismically active region is considered as a system of absolutely rigid blocks separated by infinitely thin plane faults. The system of blocks moves as a consequence of prescribed 3D motion of the boundary blocks and the underlying medium. Displacements of the blocks are determined in such a way that the system is in quasistatic equilibrium state. Block interaction along the faults is viscous-elastic while the stress is below a certain strength level. When the level is exceeded for a part of some fault a stress-drop (a failure) occurs in accordance with the dry friction model. The failures represent earthquakes. As a result of numerical simulation a synthetic earthquake catalog is produced. Both simple enough block structures and the structure which approximates the main tectonic elements of the Vrancea (Romania) region are tested to find the existence of premonitory patterns and features detected in real catalogs. The frequency-magnitude relations (Gutenberg-Richter curves) and the space distribution of epicenters are analyzed for the synthetic catalogs. The software designed is oriented to the use of multiprocessor computational complex.
The work was supported by the International Science and Technology Center (Moscow, Russia, Project #008-94).

MULTIFRACTAL ANALYSIS OF DIPMETER WELL LOGS FOR CHARACTERIZATION OF GEOLOGICAL STRUCTURES

J. Muller, A. Saucier and O. K. Huseby
Institutt for energiteknikk, Box 40, N-2007 Kjeller, Norway

We use multifractal analysis as a geostatistical tool for the characterisation of microresistivity signals produced by dipmeter well-logging tools. The signal is divided into segments of fixed length. For each segment, several texture indices characterizing the irregularity of the microresistivity signal are calculated. Plotted as a function of depths, these texture indices form what we call texture logs. We show that these texture logs can be used to distinguish geological lithofacies differing in their degree of heterogeneity.

SCALING POWER SPECTRUM OF POTENTIAL FIELDS: INDIVIDUALIZATION OF FACTORS WHICH INFLUENCE THE SCALING EXPONENT.

Tatiana Quarta (Dipartimento di Scienza dei Materiali, via per Arnesano - 73100 Lecce - Italia) Maurizio Fedi (Dipartimento di Scienza dei Materiali, via per Arnesano - 73100 Lecce - Italia) Angelo De Santis (Istituto Nazionale di Geofisica. Sezione Geomagnetismo, Via di Vigna Murata 605, Roma, Italia)

The spectral decay properties of potential fields are studied to identify the factors which can influence the corresponding scaling exponents. Synthetic models with characteristics which are intermediate between Naidu's and Spector and Grant's models, (e.g.: magnetisation sources distributions which are white random at a scale greater than the field sampling interval ; single homogeneous body, intruded into a random white source distribution), produce fields whose spectral scaling exponents can assume values in the fractal range. We show also that the scaling exponent of continuous synthetic signals is strongly influenced by their shapes. Power spectra of asymmetrical signals and signals which exhibit sharp features in the time domain, are characterised by scaling exponents which belong to the fractal range. Since the scaling exponent of the field can assume values in the fractal range even if the sources are not fractal, the analysis of the field power spectrum is not sufficient to assert the fractal nature of the source. As a necessary condition we propose to analyse also the field phase spectra because they must be random for truly fractal source distributions.

FRACTAL RIVER NETWORKS: SELF-ORGANIZED FEASIBLE OPTIMA

A. Rinaldo (Istituto di Idraulica "G. Poleni", Universitá di Padova, via Loredan 20, I-35131 Padova, Italy)
A. Maritan, M. Marani, R. Rigon, I. Rodriguez-Iturbe

A complex optimization problem related to the evolution of fluvial networks shows signs of self-organized criticality. It is fortunate that in this case key statistical features of the global optima are exactly known and extensive experimental observations are available. We show that imperfect optimal search procedures yield local optima statistically indistinguishable from those observed in nature and quite different from the global solutions. Instead, more refined annealing procedures achieve optimal states closer to the actual ground state but with significant departures from natural structures. We suggest that the dynamic, self-organized adaptation of the fluvial landscape to the geological and climatic environment corresponds to the settling of optimal structures into suboptimal niches of their fitness landscape and that the diversity implicit in feasible optimality may apply in cases of general interest. Thus natural fractal structures in the fluvial landscape are dynamically accessible, self-organized optimal states where evolution can settle in a stable manner. Such relative stability is achieved with respect to perturbations and is nonetheless reminiscent if the dynamic history, including an imprinting of its initial conditions and long-lived signatures of boundary conditions, here surrogating geologic constraints.

WHY DO EARTHQUAKES STOP?

J.B. Rundle and S. Gross (Dept. of Geol. Sci. & CIRES, CB 216, University of Colorado, Boulder, CO, 80309, USA)
W. Klein (Dept. of Physics, Boston University, Boston, MA 02215,USA)

We address the basic problem of why an earthquake of a given magnitude ceases to extend. The paradox inherent in this fundamental problem arises from the fact that as an earthquake increases in areal extent, it tends to increasingly concentrate stress at the crack tip. Because the stress intensity factor increases as the crack grows, it would seem to be increasingly difficult for the rupture to experience arrest. The resolution of this question is usually tied to the qualitative idea that the difference $\sigma^F(x) - \sigma(x)$ between classical failure strength $\sigma^F(x)$ and current stress on the fault $\sigma(x)$ varies in space, and that the growing rupture eventually encounters regions where difference between the strength and the stress is large enough to inhibit further growth. We adopt this basic picture and use it to construct a theory of Stochastic Fracture Mechanics. In this idea, extension of a shear crack depends on the existence of spatial correlations in $\sigma^F(x) - \sigma(x)$. In this talk, We present theory and simulation results that support this approach.

TRAVELING DENSITY WAVE MODEL FOR EARTHQUAKES

J.B. Rundle and S. Gross (Dept. of Geol. Sci. & CIRES, CB 216, University of Colorado, Boulder, CO, 80309, USA)
W. Klein (Dept. of Physics, Boston University, Boston, MA 02215,USA) D. Turcotte (Cornell University, Ithaca, NY)

The discovery that simple meanfield earthquake models are associated with an energy functional (JBR et al., *Phys. Rev. Lett.*, 74, 1658, 1995) prompts us to propose the "Traveling Density Wave" model for earthquakes (JBR et al., *Phys. Rev. Lett.*, 76, 4285, 1996). In this nonequilibrium model, the physics is obtained from a Lyapunov functional, which plays the same role as an equilibrium free energy functional. The Lyapunov functional is constructed by assuming that the static force balance is the Euler-Lagrange equation of a functional potential. The equations describing the evolution of sliding on the surface are then obtained by 1) functional differentiation and 2) the requirement that the system evolve continuously toward a state of greater stability (lower energy). Abrasion and wearing of the surface are modeled as a random variation in the cohesive surface energy. A variety of phenomena can be predicted that have been verified in numerical simulations and observed field data.

LOCAL SCALING OF POTENTIAL FIELDS FOR THE ESTIMATION OF DEPTHS AND STRUCTURAL INDICES OF THE MULTIFRACTALLY DISTRIBUTED SOURCES : THEORY, SYNTHETICS, AND APPLICATIONS TO AEROMAGNETIC DATA

P. Sailhac and A. Galdeano (Institut de Physique du Globe, 4 place Jussieu, 75252 Paris 05, France)

We propose a method to characterize the supposed multifractal spatial distributions of the gravity and geomagnetic potential-field anomaly sources. The Maus and Dimri (1995) equation for the scaling behaviour of the Fourier power spectrum is generalized for the local scaling behaviour of the cover-thickness measure. By the way, the analysis yields to the mapping of local estimators of the depth and scaling exponent of the sources. We discuss the intrinsic link between this scaling exponent (Hölder exponent), and the structural index used in analytic techniques such as Euler deconvolution.
Tests on synthetic signals, then on aeromagnetic data of North Algeria illustrate the method. Typically, this can be used for high resolution data as a tool to build a priori models before inversion.

QUASISTATIC RUPTURE PROPAGATION: EFFECT OF PINNING

J. Schmittbuhl (Laboratoire de Géologie, École Normale Supérieure, Paris)
J. P. Vilotte (Département de sismologie, Institut de Physique du Globe,Paris)

We develop a discrete quasistatic model of a rupture propagation along an heterogeneous plane under an anti-plane loading. The stress field along the rupture front is computed by using a pertubation approach proposed by Rice. It includes non local interactions resulting from the bulk elasticity of the medium. Heterogeneities along the rupture plane cause fluctuations of the local threshold stress. We study the rupture between two rough fractured surface by considering spatial long range correlations of the threshold stresses. Indeed, fractured surfaces are self-affine and contact between them provide a correlated stress field. During the propagation, the scaling invariance of the front shape is studied. Transient and permanent regimes are characterized. Macro-scale friction laws are obtained from the relationship between the estimate of the external load and the average position of the rupture front.

MULTIFRACTALITY OF FAULT SYSTEM OF CAUCASUS

I.R.Stakhovsky (Institute of physics of the Earth, Russian Academy of Sciences, 123810, B.Gruzinskaya 10, Moscow, Russia)

Geometry of active faults of Caucasus was investigated by the help of methods of computer graphics. Maps of faults were reproduced on a computer screen what quantized the trajectories of faults and transformed them into 2-D sets of pixels. It is shown that these sets can support the multifractal measures. The sampling estimations of $f(a)$-spectra for such measures are calculated. Singularity indices in concrete points of multifractal fields were computed by the help of algorithm of wavelet transform. The distribution of singularity indices under practically achievable resolution was compared with spatial distribution of earthquake epicentres of Caucasus. In the regions of diffused seismicity the inverse correlational relationship is revealed between the probability of appearance of the epicentre of earthquake with $3 \leq M \leq 7$ and the value of singularity index of multifractal measure characterizing the fault field in the same point.

RIVER MEANDERING AS A SELF-ORGANIZATION PROCESS

Hans-Henrik Stølum (Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK)

Simulations of freely meandering rivers and empirical data show that the meandering process self-organizes the river planform into a critical state characterized by fractal planform geometry and a mean sinuosity of π. The meandering process oscillates in space and time between a state where the river planform is ordered and one where it is chaotic. Clusters of river cutoffs tend to cause a transition between these two states and force the system into stationary fluctuations around the critical state. Comparison of the simulation result and free meandering rivers in nature, in terms of scaling statistics and mean sinuosity, yields close correspondence. This confirms that free meandering rivers are in a state of self-organized criticality.

ON DYNAMICAL ANALYSIS OF THE MAIN LITOSPHERIC PARAMETERS IN THE WHOLE TERRITORY OF HUNGARY

H.L.Szőcs and Cs.Hujber (University of "Sopron" Dept.Exact and Soc.Sci,P.O.Box 52,H-8002,Székesfehérvár,Hungary: szh@geo.cslm.hu)

The aim of our paper is a first estimation of the dynamical,as well as the non-linear behaviour of litospheric parameters in the territory of Hungary. In this purpose we used the values of velocity of recent vertical movements.In contrast to "time-series",our data form a "coordinate-series" and instead of time-delay we used "spatial-shift" which means coordinate-variation "step by step".We computed this series for the 934 values,corresponding to 934 (measurement-and interpolated) grid points and structural-functions were also calculated.The scaling parameter **p** was varyied between **1** and **10**.We stated that in our case the variations of **scaling exponent s(p)** are between 0.2669 and 1.9710 and the corresponding **fractal dimensions D(p)** are between 3.7467 and 0.5073,the average of these values are 0.7921 and 1.2615,respetively.Our preliminary conclusion is that the investigated system (with special regard to vertical-velocity) has small dimension (degree of freedom) and means a deterministic chaos.

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FRACTAL TREES WITH SIDE BRANCHING

D.L. Turcotte, (Dept. Geol. Sci., Snee Hall, Cornell Univ., Ithaca, NY 14853 USA)
W. I. Newman (Depts. Earth Space Sci., Phys., Astron., and Math., Univ. of California, Los Angeles, CA 90095 USA)

Classic studies of fractal trees have evolved from the Horton and Straeler classifications of drainage networks. Two-first order streams combine to form a second-order stream, two second-order streams combine to form a third-order stream, etc. Actual stream networks, however, also involve side branching. Tokanaga devised a matrix formulation to quantify side branching. The number of first-order streams that combine to form second-order streams is denoted N_{11} but N_{12} is the number of first-order streams that join second order streams, N_{13} is the number of first-order streams that join third-order streams, etc. Tokanaga further argued that in terms of branching ratios it was a good approximation to take $N_{12}/N_2 = N_{23}/N_3 = \ldots$ etc., $N_{13}/N_3 = N_{24}/N_4 = \ldots$, etc. Horton's law that N_i/N_{i+1} = constant and r_{i+1}/r_i = constant define a constant fractal dimension. Tokanaga's approach defines an improved taxonomy of fractal trees. Drainage networks have been shown to satisfy this extended self-similarity, DLA clusters also satisfy the same self-similarity. Space filling two-dimensional and three-dimensional constructions are given both with and without side branching.

THE AFTERSHOCK SERIES OF EVENT 18 FEBRUARY 1996. A COMPLEX BEHAVIOR?

Merce Urquizu, Josep Vila, Antoni M. Correig
Dept. d'Astronomia i Meteorologia, University of Barcelona.

On February 18, 1996, an earthquake of magnitude M=5.3 occurred at the eastern Pyrenees. Probably, this event is associated to the Agly Massif-North Pyrenees fault system, with recent tectonic activity and important historical seismicity. The continu ous digital recording broadband seismic station CAD, 80 Km apart of epicenter, allows us to perform an analysis of the aftershocks series with magnitudes greater than 1.8. As a first result the aftershock series does not fit Omiri's law. A closer look at the series show that the shape of the cumulative number of aftershocks presents changes of concavity. We define i) a "cascade" ofthose events as the events with negative concavity (defining as positive the concavity corresponding to Omori's law), and ii) the "aftershock" as a cascade of events. Thus defined, the reduced series fit quite well Omori's law with exponent p = 0.7. The events that define the cascade occur at a constant rate, and the velocity of the different cascades decreases with increasin g time, following a power law. The cascade can be interpreted as a discrete rupture of an asperity. By means of numerical experiments, we have seen that complex behavior of the original series of aftershocks can be simulated with a SOC model.

GAS BUBBLES DYNAMICS AS ORIGIN OF SHALLOW VOLCANIC TREMOR AT STROMBOLI VOLCANO

Merce Urquizu (1), Maurizio Ripepe(3). Antoni M. Correig(1)
1 Dpt. d'Astronomia i Meteorologia, Universitat de Barcelona. Marti Franques 1. E-08028 Barcelona. Spain.
2 Dipartimento di Scienze della Terra, Via G. la Pira 4, I-50121 Firenze, Italy. (maurizio@ibogfs.cineca.it)

The seismic activity of Stromboli is analyzed from records of infrasonic and tremor signals. The infrasonic signals have been decomposed into two distinct series: inter-event time between impulses and their relative amplitudes. Tremor time series and the inter-event time series have been analyzed with the classical methodology (histograms, autocorrelation and running mean test) as well as with the use of nonlinear methods (Hurts exponent and correlation dimension) and we have found that tremor ans inter-event time share the same characteristics: they are related to a system with memory and cannot be modeled through a nonlinear low dimensional chaotic system. The infrasonic impulses have can be associated with a bubble, which suffers a decompression when enters into a magmatic conduct. This decompression firts travels through the magma, and then to the surface through a stratified media, where it is recorded. A superposition of bubbles gives rise to a tremor. By means of Haskell matrix method, and using the interevent time and amplitude distribution as obtained from the infrasonic time series analysis, synthetic tremors have been generated and compared to reco rded ones: they are very similar. This similarity suggest that, at least for Stromboli, the origin of the tremor ant its spectral structure that propagates through a highly inhomogeneous stratified medium.

ELECTROMAGNETIC WAVE PROPAGATION IN A RANDOM FAT FRACTAL LAYERED EARTH.

F. Vallianatos (Technological Educational Institute of Crete, Chania, Crete,Greece & Geodynamic Institute, National Observatory of Athens)

In the present contribution, we study numerically the electromagnetic wave propagation through one-dimensional random fat fractal layered structure. This model can serve as a model of porous media or of the near surface layers of the earth. Our calculations lead to the conclusion that the behaviour of electromagnetic data measured in the earth's surface depends on the fractal exponent. In order to characterize the behaviour of the impedance we introduce its dimension which turns out to be between two and three. Furthermore, the convergence of the numerical approach is discussed.

PHYSICAL ORIGIN OF SELF-SIMILARITY IN FLUVIAL TOPOGRAPHY

D. Veneziano, J.D. Niemann, G. Tucker, R.L. Bras, F. Colaiori, and A. Flammini (Dept. of Civil and Environmental Engineering, MIT, Cambridge, MA, USA)

The scaling laws of fluvial topography reflect a basic self-similarity property whose nature and physical origin are not well understood. We analyze the symmetries of fluvial topography and conclude that, if elevation $h(x,y,t)$ is self-similar, then it should satisfy $\{h(x_1,y_1,t) - h(x_2,y_2,t)\}|_A =^d r^H\{h(rx_1,ry_1,t) - h(rx_2,ry_2,t)\}|_{\lambda A}$ where (x,y) are geographical coordinates relative to the main stream source, $|_A$ refers to a sub-basin of area A with outlet on the main stream, and $=^d$ means equality of all finite-dimensional distributions. This condition should hold for some real H and any positive r and A. Concerning the physical origin of self-similarity, we examine whether topographies that satisfy the above condition can be stationary solutions of a wide class of dynamic evolution models, the simplest of which has the form $\partial h(x,y,t)/\partial t = U(t) - \beta(z)A^m(x,y,t)S^n(x,y,t)$, where U is uplift rate, $z(x,y,t)$ is depth in the rock column, β is an erosivity coefficient, A is contributing area, S is slope, and m and n are parameters. One result we obtain is that, if $n = 2m$, $U(t)$ is any stationary process, and $\beta(z)$ is any homogeneous process, then $h(x,y,t)$ may approach a stationary configuration that is self-similar in the sense above with $H = 0$. The relation $n = 2m$ and the value $H = 0$ are supported by much theoretical and empirical evidence. The fact that this result is found under any homogeneous erosivity, any stationary uplift, and for a wide class of dynamic models seems to explain the "universal" character of topographic self-similarity (with $H = 0$) and its robustness relative to uplift rate and horizontally stratified geologic conditions.

NON-LINEAR EFFECTS IN MINERAL GEOTHERMOMETERS AND GEOBAROMETERS BY PHASE EQUILIBRIA.

D.G.Yegorov (Kola Science Center of Russian Academy of Sciences, Fersman str. 14, Apatity, 184200, RUSSIA)

The Gibbs-Duhem equations for 5-7 mineral's phases may have non-linear functions in multi-component systems (f.ex.: GR-BT-STAVR-KY-QU). It is possible if many components participate in the synthesis/destruction of several phases. The computation of this systems it was found out, that temperature and pressure are non-linear functions of chemical composition of minerals, it is even possible to observe periodical waves of concentration Mg, Fe, Mn in granats with the increase of temperature. This fact may be of utmost importance as the limiting factor of mineral geothermometers and geobarometers application in the metamorphic petrology.

Chaotic Fluctuations and Bistability - the Effects of Adiabatic Heating on Vigorous Thermal Convection

U. Hansen (Inst. f. Geophysik, Univ. Muenster, Germany)
D. A. Yuen (Minnesota Supercomputer Institute, Dep. of Geology and Geophysics, Univ. of Minnesota, U.S.A.)

We have studied the behavior of thermal convection in the presence of a strong influence of adiabatic heating. The flow has been investigated in the limit of infinite Prandtl number. Such a system resembles scenarios in which a fluid layer is characterized by a surface temperature T0 being high,as compred to the temperature drop across the layer.The Earth's outer core and the Jovian moon Io are good examples of such a system. With two-dimensional models we have explored the parameter space as spanned by the Rayleigh number Ra and the surface temperature T0. The values of Ra are ranging between 10**7 and 10**15 and of T0 between 0.2 and 5.0. For cases with a high Ra (> 10 **12) and a T0 higher than 1 the flow developed a clearly bistable behavior. The flow oscillates between one stage, charaterized by a well ordered cellular flow pattern and another one ,exhibiting a chaotic flow structure. The well-ordered stage is associated with a high heat transport, the minimum heat transport is reached in the chaotic phase. At high Ra the thermal field is dominated by the adiabatic heating ,leading to a thermal profile akin to an internally heated system. The time series of the flow amplitude resembles the features of a globally fractal series. Such systems can potentially lead to a better undertanding of geophysical phenomena with a clear bistable character , such as the geodynamo.

SE30 Investigation and reconstruction of pre-instrumental and historical earthquakes

Conveners: Gutdeutsch, R.; Papadopoulos, G.A.

COMPARISON OF INSTRUMENTAL AND INTENSITY DERIVED FOCAL DEPTHS

D.S. Brumbaugh (Arizona Earthquake Information Center , Box 4099 Flagstaff, Az, 86011 USA)

Intensity derived focal depth would be a useful parameter for historic tremors.Data from 24 earthquakes located in the U.S.(1925-1989) were used to evaluate focal depth derived from intensity. These were events with available intensity maps and well determined instrumental depths(3 to 44 Km.). Intensity derived focal depths were obtained by use of the Bath equation: $I_o = 3\log[(r_f^2 + h^2)/h^2] + 2$ and a newer modified equation : $I_o = 2.8[(2.79Av/\pi + h^2)/h^2] + 2 - 6/1.2h + (6 - I_o)/6$. The modified equation bases its estimate on the area inside the Modified Mercalli V contour, versus the Bath estimate of radius of felt area (r_f). The average difference between instrumental depth of focus and Bath estimates was 17.7 kilometers. The average difference in focal depth between instrumental and modified equation estimates was 3 kilometers. Twelve of the events differed in depth from the instrumental depth by 2 kilometers or less when the modified equation was used .

PRELIMINARY RESULTS ON THE HISTORICAL SEISMIC ACTIVITY OF THE TYRNAVOS FAULT (THESSALIA, GREECE)

R. Caputo (univ. of Pescara, Italy)
G.A. Papadopoulos (Institute of Geodynamics, National Observatory, 11810 Athens, Greece)
S. Pavlides (Dept. of Geology, University of Thessaloniki, 54006 Thessaloniki, Greece)

The Tyrnavos normal fault belongs to the E-W trending extensional tectonic system affecting northern Thessalia from the Middle Pleistocene. Along the 10-12 km long fault trace, several morphological features have been observed thus documenting a very recent activity. Among these features are fault-generated landforms (bedrock fault scarps and fresh fault scarps in unconsolidated deposits) and fault-related phenomena (faulted and truncated scree fans and a dammed river valley). Historical seismic activity is documented in the area. The 1731 shock of Io=VIII(MM) and estimated Ms=6.0 is tentatively attributed to this tectonic structure. The preliminary results of paleoseismological trenching is presented.

SEISMIC MOMENTS OF THE ITALIAN HISTORICAL EARTHQUAKES

P. Gasperini (Dipartimento di Fisica, Settore di Geofisica, Università di Bologna, Italy)

The scalar seismic moment represents the best estimator of the size of an earthquake not only because it does not saturate at high values, but principally, because it has a physical meaning strictly linked with source sizes and other measurable source parameters. Unfortunately direct seismological estimates of the moment are available only for few tens of Italian earthquakes and even geodetic-geological evaluations have been given only for not more than a couple of events. In this work the problem of how to get an affordable estimate of the scalar seismic moment has been approached for all the Italian earthquakes for which evaluations of instrumental magnitude exist and for that ones, of the pre-instrumental era, for which good macroseismic information are available. To this purpose the new data-base of the "Catalog of Strong Earthquakes in Italy, from 461 A.D. to 1990 (2)", which is going to be published by the Istituto Nazionale di Geofisica (ING) of Rome and Storia Geofisica Ambiente (SGA) of Bologna (Italy), has been used. When possible, an estimate of the uncertainty of the estimate of the seismic moment is also given.

THE HISTORICAL EARTHQUAKE OF 373B.C. IN THE WESTERN CORINTHOS GULF, GREECE

D.Katsonopoulou (American School of Classical Studies at Athens, Souidias 54, 10676 Athens)

Two cities of Achaia, Helike and Boura, were destroyed in the winter of 373B.C. because of a large shock. The systematic survey of our team in the area SE of Aigion to locate and uncover the ancient Helike since 1988, yielded new evidence for the location of the lost Achaean cities, the history of shocks and their possible reconstruction. The main data obtained are: (1)The lost Helike no longer lies underwater but is to be found under thecoastal plain, (2)Boura may be identified with a new archaeological site discovered recently south of the Zachloritika village, (3)Important data about old shocks were recovered from our underwater sonar survey in 1988 and the analysis of 46 bore holesdrilled in the plain in 1991-96, (4)In 1994, the application of magnetometry resulted in the location of the first ancient structure ever discovered in the plain of Helike, namely a building of Roman period, (5)Excavations provided evidence for the occurrence of an unknown earthquake in the late Roman period.

TECTONIC CONSTRAINTS FOR THE SEISMIC POTENTIAL OF FAULT ZONES IN THE AUSTRIAN ALPS

K. Decker (Institut für Geologie, Althanstr. 14, A-1090 Wien, Austria)
G. Gangl (Donaukraft Engineering, Parkring 12, A-1010 Wien, Austria)

Besides historical sources, geology offers additional informations on severe earthquakes of M>5.5 which are documented by surface-penetrating faults. The Austrian Alps show moderate seismicity and maximum focal intensities of historical quakes of I_0=9. A first approach of an independent independent geologic study is carried out to discriminate faults in the Alpine thrustbelt which can move in the recent stress field, and to estimate the maximum fault surfaces which could rupture in a seismic event. The fault pattern in the Eastern Alps is dominated by Miocene thrusts and strike-slip faults which formed in a N-S-compressive paleostress field comparable to the recent one. The dominantly (N)NE- and NNW-striking strike-slip fault zones display variable segmentation with about 100 km maximum lengths of individual segments. Faults in the northern Eastern Alps root in the Alpine floor thrust and do not penetrate to the basement, thus only dissecting the uppermost 0-10 km of the crust. Information about the depth range of faults also comes from rheolo-gical modeling of the Alpine lithosphere which indicates that, due to the thermal structure of the thickened lithosphere, brittle fracturing is restricted to the uppermost 10-15 km of the crust. This matches the distribution of hypocenter depths. This reasoning gives estimated maximum strike-slip fault surfaces in the order of 500 to 1000 km². An interpretation of the geologic record is not simple, but provides us with information of a longer earthquake history where written sources are not available.

ON THE SEISMIC ENERGY RELEASING IN THE TRANSFRONTIER REGION OF SOUTHWEST BULGARIA - MACEDONIA AT THE BEGINNING OF THE 20TH CENTURY

R.Glavcheva (Geophysical Inst., Bulg.Acad.Sci., Acad.G.Boncev st., bl.3, 1113 Sofia, Bulgaria)

The goal here is the quantifying the energy released at the beginning of the 20th century through the earthquake series in the border region between Southwest Bulgaria and Macedonia. It was found that the existing inventory did not differentiate the belonging seismic events correctly enough. On the basis of a Bulgarian seismological compilation, some newspapers and personal reports, the earthquakes are identified once again. By using pieces of information from the peripheral part of the macroseismic field the earthquake magnitude is assessed; in such a way the dubiousness of intensity determination in the epicentral area after a large earthquake excitation has been avoided. Several characteristic stages of the energy radiation pattern are specified.

THE INDUCED NATURAL SEISMIC HAZARDS BY HISTORICAL EARTHQUAKES IN ALBANIA

S Kociu (Seismological Institute, Tirana Albania)

Based on the data of historical earthquakes and in-situ investigations some evidences of induced seismic hazards observed on free surface as fault rupturing traces, new and induced landslides, rock-fall events and liquefaction phenomena are presented as important elements of natural hazards in seismic prone areas as the coastal area of Albania

On the other hand some evidences on tsunami phenomena observed on Adriatic and Ionian seacoast are presented as well

Based on these data and recent investigations for seismic hazard assessment at local level, a qualitative method on the reliability of these phenomena is shown

SOURCE STUDY OF THE JANUARY 15, 1858 ŽILINA (SLOVAKIA) EARTHQUAKE

P. Labák (Geophysical Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic)
Ch. Hammerl (Institute of Meteorology and Geophysics, University of Vienna, UZA II, Althanstrasse 14, A-1090 Vienna, Austria)

Basic data on the January 15, 1858 Žilina earthquake is available in the catalogues by Réthly (1952), Molnár (1955), and Kárník, Michal & Molnár (1957). An isoseismal map is also available (Procházková & Kárník 1978). Epicentral and site intensities are inconsistent in the mentioned literature, what motivated us to study the earthquake anew.
We have established the family trees from the catalogue sources, and retrieved the Jeitteles's collection (available in the Library of the Austrian Academy of Sciences), which contains 171 contemporary earthquake reports. We analysed the sources mentioned in the catalogues and a part of the documents from the Jeitteles's collection.
Conclusions: 1. The Jeitteles's collection of the documents is of crucial importance for the analysis of the earthquake. 2. There is no direct reference to the Jeitteles collection in the available catalogues. 3. The Jeitteles's (1859) report is of crucial importance for the earthquake analysis in the catalogues. 4. The absence of the entire information from the collection in the catalogues might have influenced the intensity estimation at sites.

SEISMICITY AND ARCHEOLOGY: FIRST CASE STUDY IN FRANCE.

A. Levret (Institut de Protection et de Sûreté Nucléaire, Département de Protection de l'Environnement, BP 6, 92265 Fontenay-aux-Roses, France).
Ph. Combes (Geo-Ter, Pôle Geo-Environnement, 3 rue J. Monnet, 34830 Clapiers, France).
M. Gazenbeek (Centre de Recherches Archéologiques, 250 rue Albert Einstein, Sofia Antipolis, 06560 Valbonne, France).
E. Gilli (Centre d'Etude du Karst, 13 rue Masséna, 06000 Nice, France).

In France, a country with moderate seismicity, severe earthquakes are unfrequent, and the return periods for major events may exceed the time window covered by instrumental era. Starting in 1975, a multidisciplinary program of a systematic in-depth investigation of accessible archives and a methodical analysis of the documents have led to the constitution of a vast macroseismic database. The completness of the database can be roughly estimated over the past 500 years for major events but over that time window, other investigations are required. Destructive earthquakes could have left their mark upon old constructions and archeological remains (archeoseismicity). Observations of the effects of seismic ground motion made by geologists, seismologists, and structural engineers during post-seismic investigations display similarities with anomalies noted on historic buildings and archeological sites. Such observations and investigational methods are thus applicable to archeological remains in France. A multidisciplinary study of the Roman aqueduct at Nimes is currently in progress. Damage that might be of seismic origin has been observed on this monument, i.e. cracks, warping, the collapse of one of the walls of the canal along several tens of meters in the same direction, the fall of stalactites beneath several of the canal's vaults. The analysis of these observations in relation with the space-time evolution of the monument should allow to define the event to which these disturbances are to be ascribed, but the interpretation in terms of focal parameters should have to be resolved.

HISTORICAL, ARCHAEOLOGICAL AND GEOLOGICAL DATA ABOUT THE 50 BIZONE EARTHQUAKE (NE BULGARIA)

M.Matova (Geological Institute, Bulgarian Academy of Sciences, Acad. G.Bonchev Str. Block 24, Sofia 1113, Bulgaria)

The 50 Bizone earthquake devastated a rich Greece town-colony with the cited name, founded in the NW part of the Black Sea littoral. This event happened in the region of the recent town of Kavarna, situated to the NE of the town of Varna, the greatest and the most important town of the Bulgarian seaside. The intensity of the earthquake was of the X degree according to the MSK-64 and of M=7 or M>7. The archaeological investigations established that a part of the town-colony, developed on the littoral of the Charakman hill, subsided in the Black Sea to the S of the mentioned hill and was considerably destroyed. The rest part of the town-colony was also strongly damaged. That was the main cause of the decreased significance of the cited ancient settlement. The structural investigations allowed to establish the presence of seismically active faults with E-W direction to the S of the Charakman hill, as well as some other faults with N-S direction on its eastern and western slopes. The seismic manifestations provoked the vertical block displacement and the formation of land subsidence with a total effect of some tens of meters, realized in a very short time period. The earthquake caused the gravitational phenomena as numerous landslides and some rockfalls. The epicenter of the earthquake was probably in the Black Sea area near to the Charakman hill. The seismotectonic activity of the above mentioned territory must be in relation with the recent evolution on the margins of the Moesian and the Black Sea microplates of the Balkan Peninsula.

RECONSTRUCTION OF LARGE HISTORICAL EARTHQUAKES OF THE 18TH AND 19TH CENTURY IN THE NORTHERN RHINE AREA, GERMANY

H. Meidow (SGB, Heidbergweg 21B, D-51149 Koeln, Germany)

The macroseismic effects of the earthquakes of Dueren 1755 and 1756, Tollhausen 1878 and St.Goar 1846 in the northern Rhine area, Germany, are reconstructed mainly on the basis of contemporary documents like diaries, chronicles or newspapers. The documents are weighted on one hand concerning their credibility, reliability and completeness and on the other hand concerning their information regarding intensity determination. Isoseismal maps are drawn and the macroseismic focal parameters are estimated. The reconstruction has been carried out considering the macroseismic effects of the earthquake of Roermond 1992. Especially the analysis of the observed damage to churches was a useful tool for the intensity determination of the historical earthquakes in the same area. The strongest event was the earthquake of Dueren 1756. Its macroseismically determined local magnitude ML = 6.1 was slightly larger than the local magnitude of the Roermond earthquake ML = 5.9.

ONGOING DEFORMATION AND PALEOSEISMOLOGY IN THE PAMIRS/TIENSHAN

G. W. Michel, D. Angermann, J. Klotz, Ch. Reigber (GFZ Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany)
K. Reicherter (Geol. Inst., Uni. Hamburg, Bundesstr.55, D-20146 Hamburg, Germany)

The GFZ Potsdam established a regional GPS geodynamic network in the TienShan and northern part of the Pamirs. In addition to measurements of ongoing deformation and kinematics, structures indicating recent deformation were studied both in the field and using Landsat images. Aims are to contribute to the understanding of intracontinental mountain building processes, investigate the distribution of deformation and its partitioning, compare deformation and velocities over different time scales, study both earthquake deformation and long-term kinematics, and contribute to the hazard assessment of the area. We trenched at different sites both in the northern frontal thrust of the TienShan (Isikata Fault) and in the Pamir Frontal Thrust and used geomorphic techniques to consider paleoearthquake magnitudes, frequencies and recencies of last events. Displaced paleosols were dated using 14C techniques. The contribution concentrates on earthquake deformation and will present results of the trenching studies and from 4 GPS camaigns.

HISTORICAL SEISMICITY OF AL HOCEIMA REGION

Touria El Mrabet & Nacer Jabour (Geophysics laboratory, Centre National de Coordination et de Planification de la Recherche Scientifique et Technique. B.P.8027, 10102 Rabat, Morocco)

Many studies carried out about the historical seismicity in Morocco have revealed that the region of Al-Hoceima is a foci of frequent seismic activities during many centuries, and that this region was first known as " Al- Mazamma". The most important city Bades was called "Velez de Gomera" during the Spanish era until the recent centuries when it was shifted to Al-Hoceima and Melilla. The seismic crisis that experienced the region of Al-Hoceima in 1994 is not a new characteristic element of the region, since this last one was the subject of comparable or more servere ground shaking in the past. The goal of this presentation is to give a short historical overview about the major earthquakes that occured in the region and its surroundings particularly those of 1522 and 1624, in addition to the seismic crisis which took place at the end of the XVIII century and lasted at the beginning of the XIX century (1800 - 1802). This presentation aims also to describe in parallel the human and material damages resulting from the series of earthquakes.

THE BARROW-IN-FURNESS EARTHQUAKE OF 15 FEBRUARY 1865: LIQUEFACTION FROM A VERY SMALL MAGNITUDE EVENT

R.M.W. Musson (British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK)

High intensity and liquefaction phenomena are usually associated only with relatively large magnitude earthquakes. An earthquake in 1865 in the north west of England demonstrates that a sufficiently shallow small event can also produce liquefaction. The effects are well-documented in historical sources and include sand fountaining. Modern investigation is confined to documentary evidence owing to the tidal environment of the area where liquefaction occurred. Analysis shows that the felt area of the earthquake was only about 200 km2; however, heavy damage occurred in the village of Rampside and the maximum intensity is assessed at 8 EMS. The magnitude was probably in the range 2.5-3.0 ML.

INFERENCE AND ASSUMPTION IN HISTORICAL SEISMOLOGY

RMW Musson (British Geological Survey, West Mains Road Edinburgh, EH9 3LA, UK)

The principal aim in studies of historical earthquakes is usually to be able to derive parameters for past earthquakes from macroseismic or other data and thus extend back in time parametric earthquake catalogues, often with improved seismic hazard studies as the ultimate goal. For early historical periods, and for areas where settlement or documentation are sparse, the seismologist often finds that he has only a few data points for an earthquake which nevertheless appears to be regionally significant. In such cases, it is natural that the investigator will attempt to make the most of the available data, expanding it by making working assumptions, and from these deriving conclusions by inference. This can be seen in a number of existing studies; in some cases extremely slight data are so magnified by the use of inference that one must regard the results as tentative in the extreme. Two main types of inference can be distinguished; those based on assumptions about the significance of levels of documentation, and those drawn from modern observations of seismicity. While in many cases such assumptions may very well be correct, they are usually untestable or untested. Furthermore, it is possible to produce numerous contrary examples. It is concluded that the use of inference to amplify poor data must be made very transparent to the end user of the results, to avoid misleading appearances of accuracy. In many cases it may be best to abandon the quest for parameters altogether and admit that the data are inadequate.

RECONSRUCTION OF STRONG PAST EARTHQUAKES OF THE LESSER CAUCASUS FROM SURFACE SEISMODEFORMATIONS

Nikonov A.A. (Joint Institute of physics of the Earth, RAS, 123810, Moscow, Bolshaya Gruzinskaya str. 10, Russia)
Zhidkov M.P. (Institute of geography, RAS, 109017, Moscow, Staromonetny 29, Russia)

Recent strong earthquakes occurred within the Great and Lesser Caucasus in 1988, 1891, 1992 producing large relief disturbances of two types, linear seismotectonic ruptures and seismogravitational failures. The same kinds of seismodeformations (were found in the Lesser Caucasus in epicentral areas of great historical earthquakes such as the 1139 Goek-Goel, 1679 Garni, 1840 Ararat and other events. Moreover, a number of other older relief disturbances in the form of rockslides and rockfalls have been described throughout the Lesser Caucasus. Some of them can be related to poorly known (from historical records) destructive earthquakes of 735.854.869.a.o
A special regional catalog of gravitational paleoseismodeformations has been compiled for the study's area. This catalog enables one to specify not only epicentral areas ,but also to assess the intensity and magnitudes of about twenty strong past earthquakes within the Lesser Caucasus, which were poorly known or unknown earlier. This approach leads to more reliable seismic hazard assessment of the study area on a long-term scale.

LARGE HISTORICAL EARTHQUAKES OF 1802 AND 1838 IN THE VRANCEA AREA: REVISION OF MACROSEISMIC FIELDS.

Nikonov A.A. (Joint Institute of physics of the Earth, RAS, 123810 Bolshaya Gruzinskaya str.,10, Moscow, Russia)
Korolev V.A. (Institute of Geophysics NAS,252180, Acad Palladin str., 32, Kiev, Ukraine)

Deep Carpathian earthquakes have been the subject of a special study and revision befitting the present stage of knowledge. Authors recollected primary sources to classify these in accordance with the European practice. Here we are considering large Carpathian earthquakes of 26/10/1802 M=7.5 and 23/1/1838 M=7.0 as regards their felt effects in Eastern Europe. A systematic search for primary macroseismic information in Russian and Ukranian archives, newspapers, and memoirs has dramatically increased the number of sites for wich information on these events is available for the Eastern European Platform. Much more complete and reliable (compared with past studies) intensity determinations were the basis of new isoseismal maps for these earthquakes to scale 1:2.5 mln. Special mention is due in reference to the following features of the macroseismic fields for the deep 1802 and 1838 earthquakes: 1-The fields show well-pronounced directivity in seismic radiation, the ratio between !the radii of isoseismals, Rmax:Rmin, being 1.1 to 1.9. 2-The 1802 radiation was greater towards the northeast (30(-60(), while the 1838 waves tended towards the north (350(-30(), which seems to have been due to the focal mechanisms. 3-The intensity IV shaking in 1802 propagated the most toward the northeast for 1500 km, the felt area being 870,000 km2 in the northern halfspace.

ARMAGEDDON'S EARTHQUAKES

Amos Nur (Geophysics Department, Stanford University, Stanford, CA 94305).
Hagai Ron (Geophysics Institute of Israel, Holon 58122, Israel).

New measurements of motions and earthquakes on active geological faults greatly helps explain often observed but rarely understood repeated excavated destruction. Ancient Armageddon (Megiddo), the single most excavated archaeological site in Israel, is a fascinating example for this: It is situated next to the Mt. Carmel-Gilboa fault system which is seismically active (with a M=5.3 in 1983 5 miles away). Its past activity has created the topography which made Megiddo strategically so important; and through episodic earthquakes destroyed Megiddo's walls and buildings repeatedly. The accumulated fault motion created the Nahal Iron Pass that controlled ancient traffic between Syria and Egypt. Megiddo's strategic situation at this pass led to great ancient battles and was the reason for the maintenance of its fortifications. The recurrence of damaging earthquakes, possibly 3 to 4 per millennium, explains the repeated destruction of Megiddo sometimes assigned, for lack of a better explanation, to unproved battles: e.g., King David's assumed conquest and the mindless destruction of Megiddo was actually a destructive earthquake in Northern Israel @ 1020 BCE.
Finally, the earthquake described in Revelations 17:8-18 during the battle of the Apocalypse at Armageddon is thus simply an example of a retrospective prophecy.

THE 5 NOVEMBER 1633 SHOCK IN ZAKYNTHOS : HISTORICAL AND GEOLOGICAL RECORD

G.A. Papadopoulos (Institute of Geodynamics, National Observatory ,11810 Athens,Greece)
R. Caputo (Univ. of Pescara, Italy)

The 5 November 1633 shock has been historically described as a catastrophic event in Zakynthos. In the Laganas Bay several geological effects were caused (ground failures,coastal subsidence, new islet formation). From our field trips in the last years we were able to verify in the field the reliability of the historical information the very fresh St. Sostis surface fault-break that possibly is associated with the 1633 event. The nearby neotectonic Lithakia fault has been mapped in a 1:5,000 scale and studied as for its geometry and kinematics and its possible tectonic connection with the St. Sostis fault. This is a contribution to an EARTHWATCH (USA) 1996 Project.

HISTORICAL EARTHQUAKES FELT IN THE ISLAND OF KYTHIRA: HISTORICAL DOCUMENTATION AND ARCHAEO_ LOGICAL EVIDENCE

G.A.Papadopoulos (Institute of Geodynamics, National Observatory , 11810 Athens,Greece)
A. Vassilopoulou, Athens, Greece

The area of Kythira strait, belonging to the western Hellenic Arc, is of high seismicity.Large earthquakes and tsunamis were reported during the instrumental and the pre-instrumental eras. New written documentation has been collected for a number of known and unkown historical shocks felt in Kythira Isl., such as the events of May-June 1750, June 1798, July-Sept. 1806, Apr.-June 1808, July 1838, Oct. 1889,Mar.-July 1894, Jan. 1895, Aug. 1896. Archaeological evidence has been evaluated as for its relevance to some historical Kythira earthquakes and associated tsunamis.
This is a contribution of the CEC GITEC-TWO Project, contract number ENV4-CT96-0297.

LONG-TERM EFFECTS OF EARTHQUAKES OBSERVED IN THE GEOLOGIC RECORD. EXAMPLES FROM GREECE AND CHINA.

S.B. Pavlides (Department of Geology, Aristotle University of Thessaloniki, 54006 Greece; E-mail: Pavlides@geo.auth.gr)

Active faults theoretically are in constant motion, both episodic and creep. The long-term effects of this movements can be observed in the geologic record, which reflects deformation that have occurred over long periods of time. These periods can be very long, geological history of deformation, or short enough, late Quaternary-Historical period. For a more elaborate analysis in order to recognize «instantaneous tectonic events», that is earthquakes, geological methods appear as the only way to expand seismicity research further into the past. These methods and techniques are rather limited at present, so seismologists and engineers who are going to use this kind of data and results must clearly know the erroneous ages of the events geologically determined. They are to advance in the near future.

A brief account of geological (Palaeoseismological) approach from Yianqing-Hualai active faults (China), and northern Greece, both seismically very active and «aseismic» areas reflect the need to answer question such as the recurrence intervals of strong and moderate earthquakes and the level of seismic hazard in the study areas based on geological information.

THE PYRENEAN EARTHQUAKE OF 5TH OF DECEMBER 1855. AN EXAMPLE OF ANALYTICAL TRANSFRONTIER SEISMICITY

F. Rodríguez de la Torre (Ph. Dr Geography and History. Calle Pez Austral, 7. 28007 Madrid, Spain).

Until now, the Iberian Seismic Catalogue (Mezcua and Martínez Solares, 1983) registers an earthquake occurred at 06 h 30 m of the day 5th of December 1855, with epicentre in Balaguer (Spain) and intensity hypothesis of degree VI MSK. Of other part, the French Catalogue (Vogt et al.) registers an earthquake, occurred the same day, 5th of December 1855, with epicentre in Chaum (France) and maximum epicentral intensity of degree VI-VII MSK, but occurred at 18 h 30 m (time that register also several historians of the Spanish seismicity).

After a very strict analysis of Spanish and French periodical press sources, is deduced that the day 5th of December 1855 alone existed an earthquake, occurred at 18 h. 48 m., with epicentre in Chaum (France) and intensity hypothesis of degree VII MSK, felt in a Spanish-French area of more of 100.000 sq. km. It is proposed, for the first time, a sketch of intensity map of the earthquake felt in South France as well North Spain and are offered numerous texts of the press of the month of event.

Once again, for the historical earthquakes analysis of the XVIII and XIX centuries is demonstrated the importance of the periodical press sources. Also it is demonstrated the importance of the sources' study of the countries implicate in the cases of the transfrontier seismicity

GEOLOGICAL EVIDENCES FOR THREE MAJOR PRE-HISTORIC SEISMIC EVENTS IN THE SHILLONG PLATEAU, NORTH-EAST INDIA

B.S. Sukhija, M.N. Rao, D.V. Reddy, P. Nagabhushanam, Syed Hussain, R.K. Chadha and H.K. Gupta.
(National Geophysical Research Institute, Hyderabad 5000 007, India.)

The paleoseismic investigations assume great significance in the Himalaya and adjoining regions in view of the marked seismicity, as evidenced by four great earthquakes in last hundred years, tectonics and absence of seismic records older than 120 years. This paper, for the first time, provides geological evidences for at least three additional major seismic events that are associated with the Chedrang fault in the Shillong Plateau, well known for the great 1897 Assam earthquake of M=8.7. The sites for the present study are located in the meizoseismal area of the 1897 earthquake, and within an area of 25 sq.km occupied by the alluvial deposits of the Krishnai river, a tributary of the Brahmaputra river. The seismites have been identified in the river section as tilted beds accompanied by unconformity, large sand dykes rising from the sand reservoir and penecontemporaneous sedimentation with microfractures and faults. The radiocarbon dating of the seismic events show that the events must have occurred around 500±150, 1100±200 and 1500±150 yr BP (before present), thereby suggesting a return period of about 500 yr for major earthquakes in this region, and the last two are associated with liquefaction. This area calls for further detailed studies to constrain the return period.

REINTERPRETATION OF THE 1844 EARTHQUAKE OF PALESTRINA (ITALY)

A. Tertulliani, R. Di Giovambattista, S. Opice, M. Pirro and A. Tertulliani (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143, Rome, Italy)

Historical, geological and recent instrumental information are fundamental tools in the framework of enlightening pre-instrumental earthquakes. This co-operation among disciplines has been experimented on the 1844 Palestrina (Central Italy) event, for which damage distribution and original cadastre were available. This investigation makes possible a reconstruction of all aspects useful for seismic hazard estimates. Macroseismic evaluation, seismic monitoring, geomorphological survey and urbanistic reconstruction are matched together to better stress the seismic impact in the studied area.

GEODESY (G)

G1 Monitoring of long-term gravity variations and their reliability

Convener: Francis, O.
Co-Convener: Hinderer, J.

ESTIMATION OF THE CAVITY EFFECT USING TWO DIFFERENT METHODS

L. Brimich (Geophysical Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic)
I. Kohút (Geophysical Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic)

Tidal forces generate periodic, low-frequency loading of the Earth's interior. Evaluation of tidal observations requires the knowledge of the cavity effect due to burried gallery of the tidal station. In this paper we consider a two-dimensional gallery embedded in an elastic medium and tidal stresses perpendicular to the axis of the gallery. The cavity effect was estimated using finite element method (FEM) and boundary integral method (BIM) as a practical examples for the numerical calculation the trapeziform, rectangular and elliptical gallery was used. The results obtained by both method were compared.

ABSOLUTE GRAVITY MEASUREMENTS IN THE UK AND THEIR INTERPRETATION.

R J Edge, G Jeffries, T F Baker (Proudman (Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead L43 7RA, UK)
R G Hipkin, H Hopewell (Department of Geology & Geophysics, Edinburgh University, EH9 3JW, UK)

Much of the United Kingdom coastline is low lying and subject to flooding. The design of adequate sea defences requires a knowledge of anticipated mean sea-level change and local vertical crustal movement. We are undertaking a program to observe sea-level trends from tide gauges, geocentric position(using GPS) and absolute gravity. The objectives are to investigate the combined effects of post-glacial rebound, sediment consolidation and water abstraction. Accurate measurements of absolute gravity, using an FG5 absolute gravimeter, started in 1994 and include repeat observations at a number of locations. Frequent observations have been made at Bidston Observatory over the last 30 months. These data, which represent a "first epoch" measurement of absolute gravity in the UK at a level of precision and accuracy of 3-4 microgals will be presented and discussed in terms of instrument and environmental effects.

BAYESIAN INVERSION OF FREE CORE NUTATION FREQUENCY AND Q FACTOR FROM SUPE RCONDUCTING GRAVIMETER DATA

N. Florsch (LEPCAT, Université de La Rochelle, France)
J. Hinderer (Ecole et Observatoire de Physique du Globe, Strasbourg, France)

The Bayesian inversion method presents several advantages with respect to more usual techniques like the least-square methods (generalised or not). It is mainly based on the analysis of the type of the information provided by the d ata, which is of probabilistic nature. By propagating this information through the theoretical relation linking the data to the parameters to be estimated, it provides the inversion result in terms of probability laws. We apply this proced ure to inverse the Free Core Nutation (FCN) resonance parameters. The probabilit y laws derived in this way restore then the whole information contained in the d ata and allow t o investigate the meaning of the more classical inversion results. The shape of the laws gives a good insight on the correlations existing between the parameter s. The law relative to the Q factor shows that it can easily reach large value s, and this is in better agreement with the independent results from VLBI than with the values obtained previously by least square analysis of gravimetric data. Technically th e method requires only direct calculations, but the large number of them imply h owever a large computer time consumption. In addition to synthetic cases, we apply the Bayesia n technique to retrieve the FCN parameters from the result of a tidal analysis p erformed on data from the Strasbourg superconducting gravimeter ! GWR T005.

COMPARISON BETWEEN ABSOLUTE AND SUPERCONDUCTING GRAVIMETER MEASUREMENTS I N STRASBOURG (FRANCE) AND MEMBACH (BELGIUM)

O. Francis (Observatoire Royal de Belgique, Brussels, Belgium)
J. Hinderer, M. Amalvict (Ecole et Observatoire de Physique du Globe, Strasbourg, France)
N. Florsch (LEPCAT, Université de La Rochelle, France)
J. Mäkinen (Geodetic Institute, Helsinki, Finland)

This paper will focus on the comparison between superconducting gravimeters (SG) and absolute gravimeters (AG) operating at the same site. We wi ll show results from the Strasbourg station in France as well as from the Membac h station in Belgium. Preliminary comparisons between Micro-g Solutions FG5 AG of the new generation a nd the compact-size SG GWR CO26 will be shown. We also show experimental results from other measurements done with a JILAG5 (Finnish Geodetic Institute) absolut e gravimeter at both stations. Special attention will be paid to respective noise levels in the gravity power spectrum. Taking into account the increasing importance of the ca libration method by parallel AG/SG measurements in gravimetry, we will show the impact on the calibration accuracy of the relative instruments of several parame ters which are involved in the experiment like tidal amplitude, noise level and sampling rate of gravity measurements, duration of a single comparison, number of repeated par allel registrations.

THE EFFECT OF ATMOSPHERIC PRESSURE ON GRAVITY: LOCAL VERSUS GLOBAL EFFECTS

J. Hinderer and J.P. Boy, P. Gegout, H. Legros (Ecole et Observatoire de Physique du Globe, Strasbourg, France)

One of the major sources of perturbations in the surface gravity is the atmospheric loading where both Newtonian attraction and elasticity are taken into account. A classical way to perform atmospheric corrections on gravity data is done with the help of a transfer function called barometric admittance between gravity and pressure both measured locally. We investigate the validity of this approach with the help of cross-correlation analyses between global and local gravity loading with the help of global pressure data (1.125° x 1.125°, 6 hour sampling) provided by ECMWF (European Centre for Medium Range Weather Forecasts). We will attempt to provide a physical explanation for the fact that the local admittance is not justified in some frequency bands. The influence of the atmospheric stratification will be tested with respect to the thin layer approximation. Finally we will use our global atmospheric loading model to investigate the influence in gravity of! the annual and diurnal atmospheri c waves S_a and S_1 known to be of planetary spatial extension.

PREDICTING ABSOLUTE GRAVITY METER CORRECTIONS WITH CONTINUOUS LEAST SQUARES

R G Hipkin (Department of Geology & Geophysics, Edinburgh University, EH9 3JW, UK)
L Robertsson (BIPM, Pavillon de Breteuil F- 92312 Sevres Cedex, France)

This paper deals with a post-processing technique to determine some of the systematic errors in absolute gravity meters. We first verify the Continuous Least Squares (CLS) method by predicting correctly the effect of adding the vertical gradient of gravity to the fitted equation of motion. The detailed comparison with observations quantifies the effect on the CLS approximation of gaps in otherwise equally spaced data missed data. The 'system response correction' - the change in estimated gravity due to vibrational noise - is also determined using CLS for both impulsive noise spikes and damped sinusoids. Using the CLS method means that a single correction, applicable to the overall mean, is found without accessing the original time-distance data for a second time: the correction is found directly from the stacked residuals obtained during routine initial processing. We give examples of the corrections found for for the absolute gravity meters FG5:103 and FG5:108, investigating particularly whether these corrections change with time or with the site location.

A COMPARISON BETWEEN FG5 ABSOLUTE GRAVITY MEASUREMENTS AND THE BRITISH PRECISE GRAVITY NET.

R G Hipkin, H Hopewell, K Charles (Department of Geology & Geophysics, Edinburgh University, EH9 3JW, UK)
R J Edge, G Jeffries, T F Baker (Proudman (Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead L43 7RA, UK)

The British Precise Gravity Net (BPGN) consists of 71 sites each observed simultaneously with three LaCoste gravity meters in a triple forward looping sequence, involving more than 3000 readings. 8 of the sites have been occupied by the FG5 absolute gravity meter. The fundamental assumption with a relative gravity meter is that the shape of the calibration function supplied by the manufacturers is correct but needs only a multiplying scaling factor and the removal of circular errors with known periods. Since BPGN network extends over nearly 800 mGal and the internal precision of both relative and absolute gravity meters is broadly comparable, the network provides an interesting test bed for examining the consistency of both absolute and relative gravity meters.

THE CONTRIBUTION OF THE MOTION OF THE EARTH IN SPACE TO THE GRAVIMETRIC M EASUREMENTS

S. Loyer (Observatoire de Paris, France)
J. Hinderer (Ecole et Observatoire de Physique du Globe, Strasbourg, France)

The contribution of the variations of the instantaneous axis of rotation on gravimetric measurements is investigated for various time scales, ranging from diurnal and subdiurnal periods to the Chandler period. The instantaneous axis of rotation motion is computed in order to take into account all the available information given by the VLBI measurements. A particular effort has been made in retrieving the short period contribution of the motion of the Earth in space. The centrifugal potential induces tidally coherent corrections in the diurnal and semi-diurnal frequency bands that can be listed in terms of corrections to the gravimetric factors. The influence of these corrections on the determination of the parameters of the Nearly diurnal free wobble (NDFW) are also investigated. The estimated contribution at long periods is used together with a data set from the superconducting gravimeter located in Strasbourg. The length of this data set (more than 8 years) allows then a realistic determination of the gravimetric factor at the Chandler period.

GEOPHYSICAL MONITORING OF FUNDAMENTAL CONSTANTS

Rokityansky I.I. (POB-338/7, Kiev-146, Ukraina)

Last decades variations of gravitational constant G, light velocity c, frequency F of quartz and atomic time standards vere observed in physical laboratories. That is the problem either the constants really change or some factors bring in a varying systematic error? In any case precise measurements of G, c and F are necessary for space navigation and many needs. To study the nature of G, c, F variations we need to store measurements'data adequately distributed in time (of day, year, solar and lunar cycles), space and instrument's orientation. So physisists need geophysical methodology. The project will be advanced and EGS has opportunity to initiate the study.

MONITORING MODERN CRUSTAL DEFORMATIONS IN THE SOUTHERN SIBERIA BY REPEATED ABSOLUTE GRAVITY OBSERVATIONS AND BY WATER LEVEL RECORDING.

Timofeev V.Y.[1], Arnautov G.P.[2], Taliev S.D.[3], Kalish E.N.[2], Stus Y.F.[2].

1 - Institute of Geophysics UIGGM SB RAS, Novosibirsk
2 - Institute of Autom.&Electr. SB RAS, Novosibirsk
3 - Baikal Museum SB RAS, Irkutsk

The results are presented for two regions of the Southern Siberia:Baikal rift - Irkutsk power station reservoir and south-west part of Baikal Lake; South West Siberia - Novosibirsk power station reservoir and surrounding territory. For determitation of vertical strain changes we used absolute gravity measurements with errors 0.5 - 2.0 microgal (5-20 nm/s^2); plus terrestial water level recordings in similar way the Salton Sea at the San Andreas Fault of California and the Iznik Lake at North Anatolian Fault Zone is being used. The absolute gravity results for three Novosibirsk stations between 1976 - 1996 are presented. More stable Kluchi station (the longest from coast line - 15 km) - the changes in the frame of errors 2-4 microgal. The results of 7 water level points between 1984-1990 are discussed. The absolute gravity results for Talaya station (south-west Baikal, at 7 km distance from the coast line) between 1992-1995 are presented, the changes in the frame of the error - 0.5 microgal. The results of 4 water level points (from Irkutsk to Kultuk-Talaya) between 1979-1987 are discussed. Original results for vertical movements of fault zones and different parts of earth crust are presented. The subsidence of south part of Baikal Lake (1-5 mm per year) are obtained on Baikal rift. The subsidence of central part of Novosibirsk power station water reservoir indicated that the effective viscosity of the lower crust-upper mantle in this region may be near 10^{19} - 10^{20} Pa•s.

OBSERVATIONS OF LONG-TERM GRAVITY VARIATIONS BY SUPERCONDUCTING GRAVIMETER GWR T020

H. Virtanen and J. Kaariainen (Finnish Geodetic Institute, Geodeetinrinne 2, FIN-02430 Masala, Finland)

The superconducting gravimeter GWR T020 of Finnish Geodetic Institute has been recorded since August 1994. We present the results of the long-term behaviour of the gravimeter for years 1994 - 1996. The offset corrected and despiked data was retided using the model at the site. For SA and SSA waves we have applied =1.16 and zero phase. The linear drift and the influence of the atmospheric pressure were removed. The residual curve shows clearly the effect of polar motion. Also the height of water table correlates with residuals.

G4 Improvements in satellite orbit determination

Convener: Nouel, F.
Co-Convener: Noomen, R.

EVALUATION OF THE ORBIT ERROR THROUGH COMPARISON OF STANDARD, STOCHASTIC AND REAL-TIME PRODUCTS

J.P. Berthias, A. Comps, A. Guitart, **S. Houry**, P. Laudet, A. Piuzzi (Centre National d'Etudes Spatiales, 18 avenue E. Belin, 31401 Toulouse Cedex 4, France)

Orbits computed for Topex-Poseidon with the most up-to-date models have proved their quality: the current estimate of their accuracy is about 3cm in the radial direction. However, this accuracy is not reached by means of modeling alone. Various parameters are solved for to compensate for errors in the force models, from empirical drag and 1/rev coefficients in standard solutions to empirical accelerations in the stochastic processing step involved in the production of the CNES ELFE orbit. At the extreme "real-time" orbits which result from unsmoothed Kalman filtering reflect as much of the quality of individual measurements as of the quality of the models.
Each of these filtering techniques, starting from the same models, produces orbits with different characteristics. Standard evaluation criteria (residuals analysis, intercomparisons, etc) and external analysis (altimeter cross-over statistics, etc) show that these solutions have different accuracies. Hence, the study of the differences between these orbits in terms of spectral and statistical contents, as well as geographical correlations, provides some insight in the nature and the level of the errors associated with each of these products.

USE OF DUAL SATELLITE CROSSOVERS IN SIMULTANEOUS ORBIT SOLUTIONS FOR ERS AND TOPEX/POSEIDON

H.J. Boomkamp (Aston University, Birmingham)

Dual satellite crossovers between the ERS satellites and TOPEX/Poseidon have been used in the past mainly for improvement of the ERS orbits, while keeping the TOPEX/Poseidon orbit fixed. Recently, the ERS orbit precision has come close to that of TOPEX/Poseidon and as a result it is no longer realistic to assume that the residual error in the crossover data is entirely due to the ERS radial orbit error. Only by solving for the orbits of ERS and TOPEX simultaneously within a single estimation process the dual crossover height residuals can be truly minimised. Both satellite orbits are then determined consistently within the same terrestrial reference frame, and also with respect to the other orbit in the solution. Arc lengths are limited by the stability of the numerical integration process, and to obtain adequate dual crossover density at given arc length limits it is necessary to include several consecutive arcs of each satellite in the solution, allowing crossovers between all arcs to contribute. New parameter estimation software for solving such groups of orbits has been developed at Aston University, and some results of simultaneous orbit solutions will be presented.

REPROCESSING OF ABOUT 15 MONTHS OF GLOBAL IGS DATA USING IMPROVED ORBIT MODELS

S. Botton (Institut Géographique National, Paris, France)
M. Rothacher, T. Springer, G. Beutler (Astronomical Institute, University of Berne, CH-3012 Berne, Switzerland)

The Center for Orbit Determination in Europe (CODE) is one of seven Analysis Centers of the International GPS Service for Geodynamics (IGS). During the years 1995 and 1996 many improvements were implemented into the routine processing of the global GPS network at CODE. To determine the impact of these changes on the global CODE results, a series of solutions – from January 1995 to March 1996 – was recomputed using the current version of the Bernese GPS Software.
The most important improvement was the implementation of an extended solar radiation pressure model for the GPS satellites. The comparison of the "old" and the *reprocessed* CODE solutions shows considerable improvements in the quality of the estimated GPS orbits, the site coordinates, and the earth rotation parameters. The new solutions also benefit from the fact, that in the reprocessing the initial phase ambiguities were resolved for all baselines shorter than 2000 km using the "Quasi Ionosphere-Free" (QIF) ambiguity resolution strategy supported by global ionosphere models routinely computed at CODE.

ATMOSPHERIC DENSITY MODEL EVALUATION AND PRECISE ORBIT COMPUTATION

S.L. Bruinsma[1, 2] and P. Exertier[1] ([1] Observatoire de la Côte d'Azur, UMR 6527, Avenue N. Copernic, 06130 Grasse, France. [2] Delft University of Technology, Faculty of Aerospace Engineering, Kluyverweg 1, 2629 HS Delft, The Netherlands)
R. Biancale (GRGS/CNES, 18 Avenue E. Belin, 31401 Toulouse Cedex, France)

The performance of the new DTM94, MSIS86 and the old DTM (1978) density models has been evaluated. Starlette, GFZ1 Stella and Ajisai orbits have been used in the evaluation. The rms of the SLR orbit fit is highly dependent on the choice of density model and the number of drag coefficients adjusted per orbit, although the use of an apropriate gravity field model for a certain satellite is even more important. New density models, based on DTM94 but with some extra coefficients, have been computed using the adjusted drag coefficients and a corresponding mean density. A sensitivity study of the satellite orbit for the density model components (O, N_2, He etc.) determined which components to adjust. The models are more or less 'tailored' for GFZ1 by the weight that was accorded to the GFZ1 data. A second set of density model solutions was computed using a different technique, which involved the computation of the partial derivatives of selected density model coefficients for each SLR observation. This method should be more sensitive to the 3-hourly K_p fluctuations than the use of mean densities, allowing a better determination of the coefficients depending on the geomagnetic index. The evaluation of these models will show if 'tailored' density models are feasible, or if one should stick to global modeling.

ANALYSIS OF RESIDUALS AND PARAMETERS IN GFZ-1 ORBIT MODELING

Z. Chen and R. König (GeoForschungsZentrum Potsdam (GFZ), Div.I: Kinematics and Dynamics of the Earth, D-PAF c/o DLR, D-82230 Oberpfaffenhofen, Germany)

Recent improved Earth's gravity field models have been made available by reprocessing or/and incorporation of new tracking data including laser ranging data of the low orbiting satellite GFZ-1. Using the new gravity models, achievements in GFZ-1 orbit determination can be reached with orbital fits of about 30-40 cm residual rms for 5-6 day arcs. Due to the remaining deficiencies of the force models, where the atmospheric drag plays a major role, and due to the sparse distribution of tracking data, the adjusted orbital parameters and the orbital residuals in precise orbit determination behave differently depending on the models used. This paper investigates regional effects in the station residuals due to different force modeling on the basis of precise orbit evaluations of one year of GFZ-1 data. Also the suitability of surface force and empirical parameters for force modeling is analyzed.

SLR data weighting for precise orbit determination

R.Devoti, M.Fermi, V.Luceri, P.Rutigliano, C.Sciarretta, Nuova Telespazio SpA, ASI Centro di Geodesia Spaziale "G.Colombo"- Matera, Italy
G.Bianco, Agenzia Spaziale Italiana, Centro di Geodesia Spaziale "G.Colombo"- Matera, Italy

The need of reducing the huge quantity of data acquired by the SLR stations became very early an urgent task in the history of space geodesy, having brought to the common use of data compression procedures. At present, the different features of performances of the tracking systems, among themselves and with respect to different satellites, and the increasing orbital accuracy demanded by the most recent satellite missions, drive to consider the importance of the data weighting during the analysis processes. The scope of this presentation is to highlight the critical role that data weighting plays in the estimation of satellite orbits, above all for the orbits of low satellites, and to face the problem of the optimal choice among different possible types of weights. The SLR data from typical geodetic satellites, with different orbital and physical characteristics, have been analysed and the differences in the orbit determination, where found out, are shown; particular emphasis has been given to those satellites, like Ajisai, whose estimated orbits are more sensitive to different data weighting.

Design of Filter Algorithms supporting the Orbit Determination of GFZ-1

E. Fragner, R.Weber (Institut fuer Theoretische Geodaesie und Geophysik, TU-Wien, Gusshausstrasse 27-29, A-1040 Wien, Austria)

Besides the microwave systems and VLBI, Satellite Laser Ranging is considered to be one of the major space techniques. SLR has the ability to provide the geodetic community with Earth Rotation Parameters, station coordinates and last but not least gravity field information. Especially satellites with low orbital heights like ERS-1 or AJISAI are very sensitive to high-degree gravity constituents. Therefore the orbit determination and orbit prediction at low altitudes is extremely complicated. Errors are mainly caused by deficiencies of the gravity field expansions and uncertainties of the atmospheric models. In this study we investigated the ability of filter techniques to support orbit integration at low altitudes. As an example tracking data of GFZ-1, which currently is the most lowflying laser satellite (semi-major axis about 6700 km), was used to improve the satellite's state vector stemming from dynamic orbit integration. Computations covering a span of two weeks in September 1996 were performed and finally the results of the method were compared to orbital information kindly placed at our disposal by the staff of the official GFZ-1 orbit computation center at Oberpfaffenhofen.

ADVANCES IN TOPEX/POSEIDON PRECISE ORBIT DETERMINATION USING GPS ANTI-SPOOF, DORIS AND SLR DATA

B. Haines, D. Yuan, R. Muellerschoen, S. Lichten and M. Watkins (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA)
G. Davis and G. Born (Colorado Center for Astrodynamics Research, University of Colorado, Boulder, CO 80309 USA)
P. Willis (Institut Géographique Nationale, 94160 Saint-Mandé, France)

Initial results from the GPS precise orbit determination (POD) experiment on Topex/Poseidon (T/P) demonstrated the strength of the continuous 3D GPS tracking for reducing correlated orbit errors. These early results were obtained when GPS anti-spoofing (AS) was off, and culminated in the achievement of 2 cm RMS radial orbit accuracy for T/P. Recognizing that the GPS receiver on T/P still represents a powerful POD tool when AS is on, we have focused recent efforts on processing GPS AS data alone and in combination with Doris and satellite laser ranging (SLR) data. Rapid-service precise T/P orbits with radial RMS accuracies of 3-6 cm are routinely produced at JPL with 14 to 48 hr latency and are based solely on GPS AS data. Recent experimental results suggest that the accuracy can be improved. In addition to the GPS-only solutions, we examine strategies that blend GPS/AS, Doris, and SLR data from select sites. The T/P follow-on, Jason, will carry a Doris receiver and a 16-channel codeless GPS receiver to provide precise dual frequency phase and range observables in the presence of AS; with gravity tuning and other improvements, we anticipate < 1.5 cm RMS radial orbit accuracy for Jason using GPS. Implications for other future altimetric missions will be discussed.

GRAVITY FIELD MODEL IMPROVEMENTS FROM GFZ-1 DATA AND QUALITY ASSESSMENTS

R. König, A. Bode, Z. Chen and P. Schwintzer (GeoForschungsZentrum Potsdam (GFZ), Div.I: Kinematics and Dynamics of the Earth, c/o DLR, D-82230 Oberpfaffenhofen, Germany)

Gravity field solutions including data from the low altitude SLR target GFZ-1 showed considerable improvements of the solvability of the resonant coefficients in the gravitational spectrum so far unexploited by satellite data. Incorporation of GFZ-1 data into the gravity solution however is difficult due to nuisance effects implied by the surface forces. The surface force model deficiencies have to be taken care of by proper parametrizations in the orbit model. Quality assessment of gravity field model solutions includes testing of orbital fits for various satellites, methods and results are discussed. A second way of quality assessment utilizes the analysis of gravity field representations, examples demonstrate the various features.

THE ANOMALOUS ACCELERATION AND RADIATION FORCES ACTING ON THE TOPEX/POSEIDON SPACECRAFT

D. G. Kubitschek and G. H. Born (Colorado Center for Astrodynamics Research, University of Colorado at Boulder)

Radiation forces acting on the TOPEX/POSEIDON spacecraft high gain antenna and solar array, which experiences warping due to temperature differences between front and back surfaces, are determined over the entire range of sun-orbit orientations characterized by the β' angle. The orienta tion of the spacecraft bus, high gain antenna, and solar array is achieved using attitude telemetry while curvature of the solar array is determined from temperature telemetry. The temperatures observed on orbit have been shown to induce warping with an approximate radius of curvature of 150 m. The resulting alongtrack accelerations are computed and the daily average determined in an effort to explain the anomalous accelerat ion which was observed during the first 16 cycles of the operational orbit (Marshall and Luthcke, *J. of the Astro. Sci.*, **42**, No. 2, 229-246, 1994). Results obtained for solar array warping show a strong dependence upon β' during sinusoidal yaw modes and range in magnitude from -0.15 nm/s^2 to $+0.15$ nm/s^2. Results obtained for the high gain antenna range from -0.10 nm/s^2 to $+0.15$ nm/s^2 and do not exhibit any of the distinct characteristics of the observed anomalous acceleration. This analysis is used to develop a method for modifying
the radiation force model used by the precision orbit determination team at NASA 's Goddard Space Flight Center.

ENHANCED RADIATIVE FORCE MODELING OF THE TRACKING AND DATA RELAY SATELLITES

S.B. Luthcke, S.C. Rowton, K.E. Rachlin, C.M. Cox
(Hughes STX, Lanham, MD, USA)
J.A. Marshall
(NASA Goddard Space Flight Center, Greenbelt, MD, USA)

Nominal operational orbit determination (OD) strategies model the Tracking and Data Relay Satellites (TDRS) as a homogenous sphere. In order to improve both orbit determination and prediction accuracies, a detailed TDRS spacecraft model has been developed. The spacecraft is represented as a combination of 24 flat plates. The radiative forces acting on each plate are computed and summed vectorially to produce the overall acceleration at the spacecraft center of mass. The a priori model, based on pre-launch engineering information, has been refined to better fit observed spacecraft accelerations. The final 'tuned' model, named GT5M3 (Goddard TDRS-5 Model 3), yields better fits to the tracking data, improves orbit accuracy, significantly reduces residual accelerations, and improves orbit prediction capability. The new model accounts for nearly all of the solar annual cycle correlated along-track accelerations, and has been shown to improve cross-track positioning as well.

SPACE SHUTTLE PRECISION ORBIT DETERMINATION AND LASER ALTIMETER MEASUREMENT MODELING IN SUPPORT OF SLA-1 ON STS-72

S.B. Luthcke
(Hughes STX, Lanham, MD, USA)
D.D. Rowlands, J.A. Marshall
(NASA Goddard Space Flight Center, Greenbelt, MD, USA)

On January 11, 1996, the Space Shuttle Endeavor, mission STS-72, was launched carrying aboard the first of four Shuttle Laser Altimeter (SLA) experiments. In support of SLA-1, one meter (1σ) radial precision and 1.5 meter (1σ) radial orbit accuracy have been achieved. Tracking and Data Relay Satellite (TDRS) Doppler observations and available Global Positioning System (GPS) pseudorange data have been used to both compute and assess the orbits. The TOPEX/Poseidon precise orbit knowledge, from Satellite Laser Ranging (SLR) and Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS), has been used to significantly reduce the contributions from TDRS orbit errors. These Shuttle orbits, and proper measurement modeling of the Laser Altimeter observations, have enabled the precise geolocation of the altimeter return points. Mismodeling of the laser line-of-sight pointing is the largest contributor to geolocation errors. Using the ocean surface, corrections to the line-of-sight pointing are estimated, and errors have been significantly reduced. The SLA observations are then used as another gauge of Shuttle radial orbit accuracy. This mission provides a unique situation in which many types of satellite observation data, from distinctly different spacecraft, must all be processed to achieve the science goals.

LESSONS LEARNED FROM THE SLR TRACKING OF THE LRE EXPERIMENT ON GPS-35 AND GPS-36

Erricos C Pavlis (Department of Astronomy, University of Maryland, and NASA/Goddard Space Flight Center, Greenbelt, MD 20771; e-mail: epavlis@Helmert.gsfc.nasa.gov)

NASA's Goddard Space Flight Center, the Naval Research Laboratory (NRL), the US Army Research Laboratory (USARL), and the University of Maryland co-sponsored a tracking campaign during the period October 20 to November 17, 1996 of the Laser Retroreflector Experiment (LRE) on GPS-35 and GPS-36. The campaign was timed to coincide with the period of operation of NRL at the Starfire Optical Range (SOR) at New Mexico and a second system at GGAO. This enhanced network over the US promised for increased tracking possibilities. Both sites had GPS receivers, civilian as well as Y-code. The data collected by the latter are to assess the quality of the pseudo ranges and the point-positioning solutions from such receivers. Goddard's interest has been primarily the calibration of the IGS orbits with the cm-level SLR data, the possibility of orbit determination aided by these data, the investigation of possible errors in the location of the s/c center of mass, and the attitude routine followed by the s/c during eclipse encounters. GPS-35 entered eclipse season during late November and for most of December. Since poor weather conditions resulted in limited tracking during the main campaign and because of the eclipse season being out of step, tracking was extended into 1997. We discuss results form the analysis of sub sets of the collected data using GSFC's GEODYN program to determine independent orbits, to compare with orbits computed independently from globally collected GPS data and also in combination with GPS radiometric data for a combined product.

A LONG ARC TECHNIQUE: APPLICATION TO LAGEOS

P. Rozanès, J. M. Lemoine, R. Biancale, J. C. Marty (Groupe de Recherche de Géodésie Spatiale, 14 avenue Edouard Belin, 31000 Toulouse, France)

The satellite trajectories used in space geodesy are usually computed by short arcs, whose duration rarely exceeds one week except for very high orbiting satellites (e. g. LAGEOS). Long arcs can be computed by numerical orbit integration, but they are penalized by a loss of precision due to non-conservative forces and long period perturbations errors. Nevertheless they provide a better mean to recover terms generating long period perturbation like the zonals terms of the Earth's gravity field and their temporal variations or the long period tide amplitudes.
The procedure we developped takes advantage of short arc computation in connecting consecutive arcs by constraining position and velocity given at each interruption with a certain a priori precision. Hence this linking technique (as we call it) allows us to build a long arc by computing only individual short arcs. A thorough evaluation of the technique has been first performed before we apply it to the LAGEOS orbit. The technique and some results on the recovery of the Earth's gravity field are presented.

LONG ARC PROPAGATION OF ETALON-TYPE SATELLITE.

M. Palacios, C. Calvo and B. Melendo
Dpto. Matemática Aplicada (CPS) and Grupo de Mecánica Espacial. Universidad de Zaragoza, Spain. e-mail: mpala@posta.unizar.es

This communication deals with the long-arc propagation of an Etalon-type satellite. The orbital problem is formulated in the so called ideal frame. The instantaneous motion of the ideal frame is described by means of quaternions. The propagated orbit of the satellite is obtained numerically in two different ways: 1) step-by-step integration by using a numerical method with periodicity properties or not, and 2) integration with a version of the multirevolution methods obtained by the authors. For the second case, we present the main properties of the method employed. We compare the results obtained with both methods and some conclusions about the behavior of the multirevolution method for the problem considered are given.

NONGRAVITATIONAL EFFECTS ON LAGEOS ECCENTRICITY

J.C. Ries, R.J. Eanes (Center for Space Research, University of Texas, Austin, Texas, 78712, USA)
G. Metris, D. Vokrouhlicky (Observatoire de la Cote d'Azur, 06130, Grasse, France)

A model for explaining the anomalous eccentricity excitations of the orbit of the LAGEOS~I satellite is considered. It appears that two phenomena are responsible for the major part of these residuals: (i) a small bias (approximately 1%) of the LAGEOS-1 surface mean radiation pressure coefficient, and (ii) the Yarkovsky-Schach thermal effect with a properly modeled evolution of the satellite spin axis. Minor influences are also attributed to the asymmetric reflectivity of the satellite surface and the asymmetric thermal emissivity of the Earth. The combined analysis of the along-track residuals and the eccentricity excitations allows for a decorrelation of the various Yarkovsky-type parameters. The resulting value of the Yarkovsky-Schach amplitude is estimated to be approximately is 241 picometers s-2, about twice as large as estimated in previous studies.

GPS-BASED POD FOR A 400-KM ALTITUDE SATELLITE

B. E. Schutz, Center for Space Research, The University of Texas at Austin

The Center for Space Research, in collaboration with the Texas Space Grant Consortium, the University of Houston and the University Corporation for Atmospheric Research, flew an Osborne TurboRogue dual-frequency GPS receiver on the second and third flights of the WakeShield Facility (WSF). Both flights were deployed and retrieved from the Space Shuttle with an orbital inclination of 28.5 degrees. WSF-02 was deployed in September 1995, and collected about 20 hours of free flight data at 400 km altitude. WSF-03 was deployed in November 1996, and was operated for about 3 days at 360-km altitude. The WSF-03 data were stored in a flight recorder, so at this writing the data from this flight have not yet been retrieved. The data from WSF-02 have been used to assess the quality of current gravity fields and aid in the calibration of their covariance matrices. In addition, the data have been used in experiments to improve the gravity model. The data also enable an assessment of low altitude drag and other nongravitational force models. Since methods of evaluating the accuracy of the orbit determination process are limited, extensive studies of error models using simulated data have been conducted. With these studies, preliminary assessments have been made with WSF-02 data and more detailed studies will be reported with the data collected on WSF-03.

GPS Satellite-to-Satellite Tracking and Accelerometry Aboard CHAMP: Mission Considerations and Data Simulations

Peter Schwintzer (GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany)

The German small georesearch satellite CHAMP, foreseen for launch into a 470 km high orbit in 1999, will be equipped with the American GPS receiver TRSR-2 and the French three-axis accelerometer STAR. Whereas the GPS receiver allows continuous tracking of CHAMP by the high-orbiting GPS satellites, the accelerometer measures in-situ the satellite's non-gravitational accelerations due to air drag and other surface forces. In dynamic orbit computations by numerical integration and adjustment, non-gravitational accelerations can thus be directly taken into account in order to extract the gravitational orbit perturbations for use in Earth gravity field recovery. The requirements on the accelerometer performance and the accomodation conditions aboard CHAMP such as attitude control system, orientation knowledge and center of mass offset are investigated. The threshold for an individual error source in the accelerometer's measurements and data evaluation is $5 \cdot 10^{-9}$ m/s^2 in order not to induce errors in CHAMP's orbit determination larger than 10 cm in position. The impact of the GPS-SST and accelerometer errors in precise orbit determination and gravity field recovery is numerically tested with simulated observation data.

GPS ORBIT DETERMINATION BY USING MICRO WAVE AND LASER TRACKING DATA

S.Y.Zhu , Ch. Reigber and Z.G.Kang (GeoForschungsZentrum, Potsdam, Division 1, Telegrafenberg A17, D-14473 Potsdam)

There are two types of tracking data to GPS satellites: micro wave (phase and code) observations, and laser tracking (to GPS35 and 36 only). These two types of data are used separately as well as simultaneously for orbit determinations. The test results show: (1) The orbits determined from laser data (only) can be as accurate as those provided by IGS(International GPS Service). (2) It is much easier to use Laser data (only) for a (comparatively) long arc orbit determination.As a result, the orbit predictions are better. (3) Simultaneous use of both data sets strengthens the solutions trastically

Error Analysis of the GEOSAT Follow-On Satellite Orbit Determined Using SLR and GPS Tracking

N.P. Zelensky, S.B. Lutchke, L. Gehrmann, (Hughes-STX, 7701 Greenbelt Rd, Greenbelt MD 20770, USA)
D.D. Rowlands, J.A. Marshall, F. Lemoine (Space Geodesy Branch, Code 926, NASA/GSFC, Greenbelt MD 20771, USA)

The high accuracy achieved in orbits produced for the TOPEX/POSEIDON (T/P) mission has raised hopes that orbits of similar quality can be determined for the GEOSAT Follow-On (GFO) Altimeter mission as well. Scheduled for launch in May '97, GFO will be placed in the 800 km altitude GEOSAT Exact Repeat Orbit, and will be equipped with GPS and SLR tracking, as is T/P. The GFO capability will allow precise measurement of both mesoscale and basin-scale oceanography over its 10 year mission, however, unlike T/P, its lower altitude greatly increases the computed orbit's sensitivity to gravity and non-conservative force model errors. This paper presents pre-launch orbit error analysis evaluating sensitivity to errors in both force and measurement models, and evaluating preferred solution strategies considering factors such as arc length, station network geometry, SLR/GPS data weighting, and the use of empirical acceleration parameters. Special care was taken to simulate realistic error models and tracking scenarios using GEODYN, as for example in tailoring the non-conservative force "truth" models to better represent the spacecraft geometry.

G5 Remote sensing for topography and geodynamics

Convener: Klees, R.
Co-Convener: Bamber, J.L.

MULTIRESOLUTION PHASE RECONSTRUCTION FOR SAR INTERFEROMETRY

R. Bamler — German Aerospace Research Establishment (DLR)
G.W. Davidson — Oberpfaffenhofen, D-82234 Wessling, Germany

Currently there are two different methods for phase unwrapping 'on the market': 1–D integration or residue–based branch–cut methods and 2–D integration or least squares esimation (LSE) techniques. The former ones are unable to unwrap low coherence areas, while the latter ones degrade more gracefully at decreasing coherence but tend to introduce wide area distortion.
The paper introduces a LSE phase unwrapping algorithm that uses multiresolution local frequency analysis. It is able to adapt its resolution to the local interferogram coherence and is asymptotically unbiased. The presented method is especially useful to compute a coarse phase estimate, i.e. one with low resolution and low probability of error propagation due to residues. The coarse phase estimate is valuable for several steps in InSAR processing:
(1) An interferogram 'flattened' using the coarse phase shows only little residual phase variations and reduced residue density. Multi–looking can then be safely applied without reduction of fringe visibility.
(2) Interferogram flattening supports accurate coherence estimation.
(3) The coarse phase map allows for an elegant implementation of slope–adaptive spectral shift filtering. It will be shown that this improves interferogram quality in critical terrain.
Phase unwrapping results for both simulated fractal scenes and real data will be presented.

IMPLEMENTATION OF A QUALITY ESTIMATION PROCEDURE FOR SAR INTERFEROMETRIC DATA

R•FCdiger Gens
International Institute for Aerospace Survey and Earth Sciences (ITC)
P.O. Box 6, 7500 AA Enschede, The Netherlands
Phone: 31-53-4874412, Fax: 31-53-4874336
Email: gens@itc.nl, Internet: http://www.itc.nl/~gens

SAR interferometry is becoming a widely used technique for a number of geoscientific applications by providing various types of information based on the phase information from radar imagery. Especially coherence images and digital elevation models are requested by the geoscientific community. For the use of any interferometric products, it is essential to have a quantitative measure for reliability of the results. A common approach to derive this quality measure is the comparison of the interferometrically derived data set with an existing reference data set. Due to problems with the availability and the required accuracy of suitable reference data, a new approach has been developed, which is independent of any reference data. This paper describes the implementation of a quality estimation procedure for SAR interferometric data based on an error propagation model. First results from the implementation are shown by means of examples.

Interpreting the impact of climate change on ice sheets using radar altimetric observations

B. Legrésy and F. Rémy
(UMR5566/GRGS, CNES-CNRS-UPS, TOULOUSE, FRANCE)

The ERS-1 radar altimeter observations cover 80% of the antarctic ice sheet. The radar observations (both waveform shape and backscattering coefficient) give useful informations on snow surface characteristics, such as surface roughness, internal stratification or ice grain size. These geophysical parameters are required for meteorological studies, for snow metamorphism studies or for mass balance survey (combined with the height measurement). Moreover, we show that snow surface conditions get short scale spatio-temporal variations which strongly affect the retrieval of the height from the altimetric waveform. These effects, whose induced error on the height estimation are within the meter, may compromise any attempt to detect temporal ice sheet elevation changes.
Moreover, climate change on ice sheets induces changes in accumulation rates and thus in ice sheet elevation, but also changes in katabatic wind pattern and surface processes. The long term evolution of these terms have direct (via the distribution of precipitation) and indirect (via changes in surface radar properties) effects on the height evolution as seen by satellite radar altimeters. Study have then to be performed in order to separate both effects, and follow both evolution.

HEIGHT DETERMINATION OF A LOCAL GREENLAND ICE CAP FOR CLIMATE MONITORING

C.S. Nielsen, R. Forsberg, K. Keller (National Survey and Cadastre, Rentemestervej 8, DK-2400=20 Copenhagen NV, Denmark)

In the summer of 1996 the National Survey and Cadastre, KMS carried out an airborne laser altimetry survey (which included 'On-The-Fly' GPS positioning) over the Geikie Plateau - a small irregular ice cap situated at 70N; 24W on the east coast of Greenland. Ground truth GPS measurements were done as well for control and calibration. These data and local airborne EMISAR data have been used to create reference height data and control points for a DEM made from INSAR images originating from the ERS-1/2 tandem mission. The aim of this study is over a period to determine changes in elevation of the Geikie Plateau.

OPTICAL CHARACTERISTICS OF GEOLOGICAL OBJECTS AND AIRPHOTOGRAPHS INTERPRETATION

Kornus A.A. University of Kharkiv, Dept. of Geography, 4, sq. Svobody, 310077, Kharkiv Ukraine.

Obtaining objective quantitative characteristics of geological objects is rather present day task because of the problem of automation of interpretation the earth surface geological structure.The aim of our work was to study optical properties of geological objects by means of their microdensitometering analysis. The airphotographs of locality in scale 1:10.000 was done for that. Two types of plots were taken for research. Some plots were chosen to analyse optical fields of the substance that has different structure but from identical relief, the others, for analysing optical fields of geological objects with the substance of same type but different microrelief structure.As a result of experiment the indications good for description optical fields of geological objects were determined.These characteristics are also classificative signs of heterogeneous objects and favour the solution of the problem of automatized processing airphotographs results.

RADAR INTERFEROMETRY AND ITS APPLICATION TO CHANGES IN THE EARTH'S SURFACE

DIDIER MASSONNET (Centre National d'Etudes Spatiales, 18 Ave. E. Belin, 31055 Toulouse Cedex, FRANCE)
KURT L. FEIGL (Centre National de la Recherche Scientifique UMR 5562, 14 Ave. E. Belin, 31400 Toulouse, FRANCE)

Geophysical applications of radar interferometry to measure changes in the Earth's surface have exploded in the early 1990s. The interferogram resulting from two radar images acquired at two distinct times is a contour map of the change in distance between the ground and the radar instrument. These maps provide an unsurpassed spatial sampling density (~100 pixels/km^2), a competitive precision (~1 cm) and a useful observation cadence (1 pass/month). They record movements in the crust, perturbations in the atmosphere, dielectric modifications in the soil, and relief in the topography. They are also sensitive to technical effects, such as relative drifts in the radar's trajectory or variations in its frequency standard. We describe various contributions in an interferogram and explain the techniques for calculating and manipulating interferograms from various radar instruments, including the four satellites currently in orbit: ERS-1, ERS-2, JERS-1 and RADARSAT. We suggest some guidelines for interpreting an interferogram as a geophysical measurement: respecting the limits of the technique, assessing its uncertainty, recognizing artifacts and discriminating different types of signal. We then review results related to earthquakes, volcanoes and glaciers using ERS-1 data. We also show examples of monitoring landslides, subsidence, and agriculture. In addition, we consider subtler geophysical signals such as postseismic relaxation, tidal loading of coastal areas, and interseismic strain accumulation. We conclude with our perspectives on the future of radar interferometry.

Comparison between Seasat and ERS ice sheet observations

F. Rémy and B. Legrésy
(UMR39/GRGS(CNES-CNRS),18 av E. Belin TOULOUSE CEDEX 31055 FRANCE; e-mail: remy@pontos.cst.cnes.fr)

Mapping geometric changes over ice sheet surface between Seasat (1978) and ERS-1 (1991-) is affected by an impressive budget error. As a matter of fact, most of the classical errors in altimetry above ice sheet are very dependent on the mission (orbit, antenna characteristics...). For instance, the so called slope error depends on the satellite height, the surface/subsurface convolution depends on the antenna characteristics, the height estimation with the same retracking is also dependent on antenna characteristics. Moreover, temporal variations of snow surface characteristics may hide a geometric change in the elevation.
However, one can be tempted to try to compare Seasat and ERS-1 topographies. The geographical pattern of the difference is indeed interesting and does not seem to be due to error.

DEM generation and ice surface change estimation by SAR interferometry

Karl-Heinz Thiel, Xiaoqing Wu, Philipp Hartl (Institute of Navigati on, University of Stuttgart, 70174 Stuttgart, Germany, Tel: +49-711-1213402, Fax: +49-711-1212755, e-mail: wu@nav.uni-stuttgart.de)

SAR-interferometry proved to be a promising technique for digital elevation model (DEM) generation and surface change estimation. It will be shown in this paper that the DEM generated from ERS-1 SAR data by SAR interferometry (INSAR) under appropriate conditions has a very good accuracy of about 4 m with respect to the real official DEM in a region near Bonn, Germany. The DEM of remote regions covered with ice such as the Antarctic areas can be also estimated by use of INSAR. By using ERS-1 SAR datas ets collected in Jan. 1992 from ascending- and descending- orbits, the horizontal ice surface movement of Filchner-Ronne-Ice-Shelf around Hemmen Ice Rise on the Antarctic is estimated with an accuracy of about 1 cm/3 d ays. The surface changes resulting from the active Vatnaj÷kull volcano in Iceland, which erupted recently, is observed by INSAR. The surface rising up and dropping down within one day due to the volcano activities can be estimated with an accuracy of 1 cm order by use of ERS-1/ERS-2 tandem data collected in the past one year from Dec. 1995 up to Oct. 1996.

INSAR TOPOGRAPHIC MAPPING - A BAYESIAN APPROACH

A. J. Wilkinson and M. Datcu (German Aerospace Research Establishment (DLR) D-82230 Oberpfaffenhofen, Germany)

The classical approach to topographic reconstruction using SAR interferometry involves a number of distinct stages: SAR focusing, image registration, interferogram formation, phase unwrapping, baseline estimation and phase to height conversion. Not only do existing InSAR processors employ this approach, but it is generally portrayed in the literature as the correct approach to the problem. In this paper an alternative view of InSAR as a Bayesian estimation problem is presented. It is argued that in principle, the correct way to view the InSAR reconstruction problem is as one large and holistic Bayesian estimation problem. Bayesian estimation theory is applicable because the InSAR reconstruction problem is a fundamentally ambiguous ill-posed inverse problem and the Bayesian approach provides a formal mechanism for resolving the ambiguities through inclusion of prior knowledge about the nature of the topographic surface. Application of the Bayesian approach involves devising: (1) a model relating system geometry, surface topography and reflectivity to the measured radar signals, (2) a stochastic model of the topographic surface embodying the dominant terrain characteristics of slope and curvature and (3) a stochastic model of the surface reflective properties. This information is combined into a conditional probability density function of the model parameters given the measured data. The InSAR estimation problem becomes that of finding a set of model parameters which maximize this function. System models are proposed, and the task of optimizing the resulting objective function is discussed.

ELEVATION CHANGES IN ANTARCTICA AND GREENLAND 1991-1996: IMPLICATIONS FOR ICE SHEET MASS BALANCE

D.J.Wingham and A.L.Ridout (Mullard Space Science Laboratory, Department of Space and Climate Physics, University College London, Holmbury St. Mary, Dorking RH5 6NT, U.K.)

The uncertainties in the mass balances of the ice sheets of Antarctica and Greenland, 5 x 1014 kg yr-1 in the case of Antarctica and 1.7 x 1014 kg yr-1 in the case of Greenland, are the largest uncertainties in the causes of the observed rise in sea level. While Antarctic and Greenland contributions to sea level to 2100 from a warming atmosphere are largely expected to cancel, understanding the surface mass balance of the Greenland Ice Sheet in a warming climate is important, because ablation is a major factor in the balance. The uncertainty in the mass balance of Antarctica has increased in time as the estimated role of ice shelf bottom melting has grown. The past few years have seen dramatic improvements in the force modelling of altimeter satellites and improved correction of the surface and volume scattering contribtions of ice sheet altimeter echoes. In consequence, we have been able to constrained the 1991-1995 Antarctic mass balance to 80 Gt yr-1 (4% of the mass turn-over) using the ERS series of altimeter satellites, and are currently performing the same experiemnt for Greenland. The estimation of the relative contributions of the surface accumulation and ice flow is important in order to estimate the mass balance outside the observation interval, and we are using European Centre for Meduim Range Weather Forecasting (ECMWF) estimates of accumulation to achieve this. In this paper, the recent advances in techniques will be reviewed, and the results from Antarctica and Greenland will be described. Using the hindcast accumulation and climatological mean estimates, the implications of the measurements for the future contribution to sea level of these ice sheets will be estimated.

OA6/G6 Ocean modelling from altimetry and remote sensing

Convener: Knudsen, P.
Co-Convener: Le Traon, P.Y.

TOPEX-POSEIDON DATA ASSIMILATION IN AN OCEANIC GENERAL CIRCULATION MODEL OF THE TROPICAL ATLANTIC

S. ARNAULT (LODYC, UMR 121 CNRS/ORSTOM/UPMC, Tour 14-2, case 100, 4 place Jussieu, 75252 Paris Cedex 05, France)
E. GREINER (CERFACS, 42 avenue G. Coriolis, 31055 Toulouse cedex, France)

One year of TOPEX/Poséïdon altimeter sea level anomalies, eXpendable BathyThermograph temperature profiles, Sea Surface Salinities and Temperatures have been assimilated into a non-linear primitive equation model of the tropical Atlantic ocean during 1992-1993. The results are analyzed by comparison with reference data sets such as the CITHER 1 data set. The emphasis is on thermal, salinity and current structures in the upper layers of the tropical Atlantic. Analysis of transports has also been conducted, especially in the North Equatorial CounterCurrent area.

ASSIMILATION OF ALTIMETER DATA INTO A PRIMITIVE EQUATIONS MODEL USING A REDUCED ORDER KALMAN FILTER

J. Ballabrera-Poy and J. Verron (MEOM/LEGI, UMR CNRS 5519. BP 53X, 38041 Grenoble Cédex, France)

A Singular Evolutive Extended Kalman (SEEK) Filter is used to assimilate satellite altimeter data into a Primitive Equations model (the SPEM model, Haidvogel et *al.*, 1991). Experiments with simulated altimeter data are performed in a 4 layer adiabatic version of the model. Resolution is fine (20 km). Thus, the chosen physical parameters are typical of the intense mesoscale activity of the oceanic mid-latitude gires.

The SEEK filter (Pham et it al., 196) is a simplification of the classical Extended Kalman Filter, in order to avoid the problems due to the numerical cost of the assimilation algorithm. To do so, it is assumed that the estimation error covariance can be approximated by a singular low rank matrix. This is equivalent to selecting a finite number of directions (in the state space) in which the model trajectory will be corrected.

In a first step, we study a degraded form of the SEEK filter, in which the functional basis of reduced order is constant in time. In following experiments, we study the case for which this basis evolves in time, to best represent the fastest growing error components, which is one of the original features of the SEEK filter. The evolutive case is found to perform better than the static filter.

DYNAMICS OF NORTH ATLANTIC MODELS (DYNAMO): EDDY STATISTICS FROM MODELS AND TOPEX-POSEIDON

B. Barnier, (Laboratoire des Ecoulements Géophysiques et Industriels, CNRS UMR 1509, BP 53, 38041 Grenoble, France)
A. Beckmann (AWI Bremerhaven, Germany), Y. Jia (SOC, Southampton, United Kingdom), C. Dieterich and P. Hermann (IFM Kiel, Germany), and the Dynamo Group.

The European MAST-II DYNAMO project aims at an improved simulation of the circulation in the North Atlantic Ocean by comparing three eddy-resolving models with different formulations for their vertical coordinate (using fixed horizontal levels isopycnic layers, and topography following (sigma) coordinate). The models are forced by ECMWF monthly mean fluxes. Model configuration have been set up to be as nearly similar as possible for all models. Each model have completed a 15-year spin-up integration, followed by an additional 5-year intercomparison experiment. Solutions from the various models are compared with respect to their ability to reproduce important aspects of the circulation in the North Atlantic. We shall discuss the eddy activity of the various models, in particular the geographical and vertical distribution of eddy kinetic energy and sea surface height, and will compare it with altimetric estimates of similar quantities obtained from Topex/Poseidon. Already, we observed significant differences between models, and between models and altimetry, related to the different solutions they propose for the Gulf Stream system, the eastern basin dynamics, and to the different subgridscale parameterizations.

THE AGMASCO AIRBORNE GRAVITY AND AIRBORNE ALTIMETER SURVEY IN SKAGERRAK

L. Bastos (Observ, Astronomico, Monte Virgem, 4400 Vila Nova de Gaia, Portugal)
R. Forsberg (National Survey and Cadastre, DK-2400 Copenhagen, Denmark)
A. Gidskehaug (Inst. of Solid Earth Physics, Alle'gt. 41, N-5007 Bergen, Norway)
K. Hehl (Technische Fachhochschule Berlin, Luxemb.st, D-13353 Berlin Germany)
U. Meyer (Alfred-Wegner-Institut, Columbussstr, D27568 Bremerhaven, Germany)
L. Timmen (GeoForschungs Zentr., Telegrafenb. A17, D-14473 Potsdam, Germany)

The MAST3 project AGMASCO organized in September 1996 an airborne gravity/altimeter survey in Skagerrak employing the AWI Dornier 228 aircraft 'Polar4'. The airborne equipment include an upgraded LaCoste & Romberg air-sea gravity meter, a laser and a radar altimeter ,two geodetic GPS receivers and a data logging unit. The main goal was to establish an operational system to model the geoid and sea-surface topography by means of airborne gravimetry, airborne altimetry and carrier phase differential GPS. The system may prove to be an alternative remote sensing tool of ocean currents and a useful supplement to satellite altimetry in coastal areas where satellite data are lacking or of bad quality. Flight- and hydrographic ship-measurements (ADCP & CTD) were carried out simultaneously on an ERS-2 track crossing from Denmark to Norway, followed up by ground truth marine gravity measurements . Tidal and meteorological effects are modelled to correct altimeter data and in-situ ADCP measurements. The airborne system of the Skagerrak campaign will be presented together with gravimetric and oceanographic results

VARIABILITY IN THE SOUTH-EAST INDIAN OCEAN FROM T/P AND ERS1 COMBINATED DATA

F. Birol And R. Morrow (GRGS, 14 Av. Edouard Belin, 31400 Toulouse, France)

We seek to monitor the variability in the South-East Indian Ocean from altimetry by combining ERS1 and T/P data (1993). This region is important for climate studies, in relation to the interannual variations of the tropical oceans and atmosphere. The eastern Indian region is directly affected by the strong seasonal monsoons, which induce a seasonal ocean variability. Moreover, the Indonesian throughflow provides another ocean forcing between the Pacific and Indian Oceans. As a result, the dynamics of the southeast Indian ocean are unusual: the mesoscale variability off western Australia is very large for an eastern boundary and the cold equatorial upwelling doesn't exist.

T/P altimeter data provide a good means of accessing the long wavelength ocean variability. The combinated ERS1 and T/P data will be analysed and compared with mapped T/P data alone, in particular to better describe the mesoscale signal, on seasonal and interannual timescales. This is important on this eastern boundary as the likely source of the westward propagating band of high energy between 20-35°S.

ASSIMILATION OF TIDE GAUGES AND XBT IN A TROPICAL OCEAN MODEL USING ADAPTIVE KALMAN FILTERING.

Isabelle Blanchet, SHOM/CMO

The Kalman filter (KF) is the optimal linear assimilation scheme when the first and second order statistics of the observational and system noise are correctly specified. Unfortunately, these statistics are usually not known. Optimality can be reached in principle by using an adaptive Kalman filter (AKF) which estimates both the state vector and the error statistics. The KF has to be implemented in a space of reduced dimension for computational savings.

The proposed adaptive algorithm has been tested using a twin experiment approach with simulated sea level data. The tropical ocean model is the Cane and Patton linear model. The AKF performance has been proven for different noises : white system and observational noise but also auto-correlated sytem or observational noise.

The AKF has been used to assimilate real tide gauge observations and dynamic height anomalies derived from XBT data. We present the results of the assimilation with this new AKF scheme compared to standard KF assimilation with a priori statistics.

DEVELOPMENT AND FIRST RESULTS OF AN AIRBORNE GEOID MAPPING SYSTEM FOR COASTAL OCEANOGRAPHY (AGMASCO)

T.Boebel and U.Meyer (AWI, Columbusstr., D-27568 Bremerhaven, Germany)

An airborne gravity and altimetry system has been developed and implemented in the research aircraft Polar-4 of the Alfred Wegener Institute. This installation is designed to operate in regions where satellites - due to their large footprint - are not able to resolve the local structures.

Differential GPS (DGPS) and an Inertial Navigation System are used to obtain a precise position and orientation of the aircraft. This high-accuracy navigation system provides the means for the determination of a local geoid model. Furthermore, in combination with altimetry measurements, the temporal surface topography can be determined. A few centimeters of surface elevation can be resolved. This implies, that sea surface disturbances due to oceanic currents can be detected.

A first regional survey has been carried out over the Skagerrak in September 1996. During the Skagerrak campaign, gravity and oceanographic measurements were performed simultaneously by the Norwegian research vessel HAKON MOSBY, our airborne survey and additionally satellite altimetry. The main objectives of this campaign were the determination of a precise geoid model and the detection of oceanic currents, by using this system in comparision to acoustic doppler current profiler measurements and to a circulation model. This model is run by the Norwegian Meteorological Institute. First results will be presented.

ALTIMETRIC ESTIMATES AND OCEANOGRAPHIC MODELS OF OCEAN DYNAMIC TOPOGRAPHY - COMPARISON OF A THREE YEARS TIME SERIES

W.Bosch, M.Kiesmüller, J.Bock (Deutsches Geodätisches Forschungsinstitut, Abt. I, Marstallplatz 8, D-80539 München, Germany)

Satellite altimetry provides a repeated, fast, global and precise monitoring of the ocean surface. For longer wavelength the geoid, computed from improved Earth gravity models, can provide similar precision. This suggests to estimate the absolute dynamic topography from the differences sea surface minus geoid. On the other hand, high resolution results are available from hydrodynamic modelling. In the present paper we compare the results of both, the altimetric estimates and oceanographic modelling.
For this comparison a series of 107 ten day gridded mean sea surface topographies has been derived from the differences of Topex/Poseidon altimeter data and the geoid computed from the new high resolution EGM96 gravity field model. The series covers a period of three years. For the same grid and ten day sequence corresponding topographies were derived by resampling the surface elevation as provided by the POCM of Semtner & Chervin. The differences are analysed with respect to both, the geographical and temporal distribution. Results are illustrated and discussed.

REGIONAL SEA SURFACE DETERMINATION BY USING AIRBORNE LASER TECHNIQUES

Cocard, M., A. Geiger, H.-G. Kahle
(Geodesy and Geodynamics Lab, ETHZ, CH 8093-Zuerich)
G. Veis, P. Milas
(Higher Geodesy Lab, NTU Athens, Greece)

Satellite altimetry is a widely used and well established method to recover sea surface on a large scale. In regions adjacent to the coast, in small water basins or in dense archipelagos, however, difficulties in determination of the sea surface by satellite ranging may be encountered. To fill this gap an integrated, small-dimensioned Laser-Profiler system, including precise DGPS and attitude sensors, was implemented the Twin-Otter of the Swiss Directorate of Cadastral Survey. In-flight calibration procedures have been developed and extensively tested over lakes. Powerful OTF algorithms constrain aircraft's position to the 10 cm level even on long offshore tracks. Extensive measurements have been carried out over the Ionian Sea. Deployment of GPS-equipped buoys, offshore and nearby tide gauges, allow accurate calibration. The measurements cover an area of high tectonic interest. They extend in a 60 miles wide stripe offshore the west coast of Greece from the islands of Corfu to Crete. After removing hydrostatic and tidal effects a good agreement of geoidal undulations between different models has been obtained. It is furthermore planned to compare ERS 1/2 radar altimetry tracks with the airborne laser results.

A HIGH RESOLUTION QUASI-GEOSTROPHIC MODEL OF THE NORTH EAST ATLANTIC ASSIMILATING ALTIMETRY - OCEANOGRAPHIC RESULTS AND COMPARISON TO SEMAPHORE DATA

E. Dombrowsky (CLS Space Oceanography Division 18 Av. E. Belin 31055 Toulouse Cedex)
S. Giraud (BRESM 14 Av G Coriolis 31057 Toulouse Cedex)

A high resolution (1/10th degree) quasi-geostrophic model of the North East Atlantic assimilating altimeter data from TOPEX POSEIDON and ERS satellites has been developped. This model coverage ranges from 24° N to 54° N and 35° W to the coast. There are ten levels on the vertical. This model was derived from the Blayo et al (1994) model. The assimilation scheme belongs to the Optimal Interpolation family and has been developped by P.
De Mey (pers. comm.). The inverse solution for this area by Paillet and Mercier (1996) is used at the open boundaries and for the assimilation of altimeter residuals. This model is aimed at being used in real-time with fast delivery altimeter data by the French Navy. Oceanographic results from this model are presented. The comparison with in-situ data collected during the SEMAPHORE (Aymard et al. 1996) in summer and fall 1993 are also shown.

REDUCED KALMAN FILTER APPLIED TO ALTIMETER DATA ASSIMILATION ON NORTH ATLANTIC

Sylvain Carme and Dinh Tuan Pham (Laboratoire de Modélisation et Calcul, C.N.R.S., Université de Grenoble, B.P. 53X, 38041 Grenoble Cédex, France)
J. Verron (Laboratoire des Écoulements Géophysiques et Industriels, URA 1509 CNRS, BP 53X, 38041 Grenoble Cédex, France)

We implement a singular evolutive extended (SEEK) kalman filter on a realistical model of north Atlantic, in order to assimilate altimeter mesurements of TOPEX/POSEIDON. The model, developped in Grenoble (SIMAN), is an high resolution (20 km) wind driven quasi-geostrophic model with bottom topography.
First, the reduction of a classical extended kalman filter consists in approximating the error covariance matrixes by low rank singular matrixes. This is realised by an EOF analysis of a reference experiment in order to initialise the filter with the covariance matrix represented by the r first EOFs and to reduce the initial error by projecting it on these EOFs. Then the subspace of correction has to be the best approximation as possible of the fastest growing error directions, in the phase space. According to the extended filter, the evolution of these directions is governed by the tangent linear model.
In our case, we try to improve the extended filter by using a dynamic, for the directions of correction which does not neglect the non linearities of our model: we represent the error evolution by a sample of $r + 1$ points which follow the dynamic of the model.

THE AGORA PROJECT : DATA ASSIMILATION IN GLOBAL OCEAN MODELS FOR CLIMATE STUDIES

P. De Mey (GRGS, 18 Avenue Edouard Belin, 31401 Toulouse Cedex 4, France)

AGORA is a project funded by the European Commission ENVIRONMENT programme. The main scientific partners are P. De Mey (GRGS, France), G. Evensen (NERSC, Norway), K. Haines (U. Edinburgh, UK), P.-Y. Le Traon (CLS, France), A. Navarra and N. Pinardi (CNR/IMGA, Italy), P. Rogel (CERFACS, France), and D. Webb (IOS, UK). The goals of the project are to perform global ocean data assimilation and prediction with altimeter, SST, and subsurface Levitus (1994) data in 1987-94; to test the quality of ECMWF reanalyses in forcing the global models; to provide initial conditions for seasonal forecasting studies in other projects; and to help intercompare innovative assimilation methods such as multivariate reduced-order optimal interpolation, the Derber and Rosati (1989) method, ensemble Kalman filtering, and the Lagrangian water displacement method. Medium-resolution, global primitive-equation models with various vertical coordinate systems have been set up. A special global altimetry dataset with TOPEX/POSEIDON, ERS-1, and ERS-2 data corrected for the long-wavelength residual errors is being produced and compared with the global integrations in forced and coupled mode. The comparison focusses on the characterisation of the seasonal cycle of the wind-forced variability and surface heat/salt storage (steric effects) in the surface topographic signature. On the other hand, twin experiments assimilating simulated data are under way, and give insight on differences of behaviour of data assimilation schemes in the tropics and in the mid-latitudes. Complementary studies regarding the statistical vertical multivariate structure of ocean variables in the tropics are carried out in the Pacific using TOGA/TAO, SURTROPAC, and model data. The talk will provide an overview of the most recent relevant results obtained by investigators, and serve as an introduction to talks on more specific aspects.

AN IMPROVED MAPPING OF SEA LEVEL VARIABILITY USING T/P, ERS-1 and ERS-2 DATA COMBINATION.

N.Ducet (C.L.S,. Space Oceanography Divivsion, 18, Avenue Edouard Belin, 31055 Toulouse Cedex, France; e-mail : ducet@metis.cnes.fr).
P.Y LeTraon (C.L.S,.Space Oceanography Division, 18, Avenue Edouard Belin, 31055 Toulouse Cedex, France; e-mail : letraon@metis.cnes.fr).

Since the launch of TOPEX/POSEIDON (T/P) in August 92, several altimetric satellites (T/P, ERS-1, ERS-2) are flying simultaneously. The situation is likely to recur in the future with missions like GEOSAT Follow On, ENVISAT, and JASON. While T/P unprecedented accuracy has provided a new picture of the ocean, its not possible to observe the full spectrum of the ocean movements with only one satellite; to resolve the mesoscale ocean circulation, another altimetric mission, at least, is then needed. The ERS satellites are thus an excellent complement of T/P sampling.
As part of the AGORA European project, CLS Space Oceanography Division is in charge of producing a combined and homogeneous data set of high quality altimetric data from 1992 onwards which will form a core period for special studies. Then, analyses of high resolution sea level maps obtained with T/P and ERS-1/2 separately and then with the combination of the three different data sets are performed to analyze the consistency of those data sets and the additional information provided by the merging of the data. Results of the merging of TOPEX/POSEIDON, ERS-1 and ERS-2 will be presented.

MESOSCALE VARIABILITY OF THE SEA SURFACE HEIGHT IN THE NORTH ATLANTIC AS MEASURED BY TOPEX/POSEIDON

S. Esselborn (Institut für Meereskunde, Universität Hamburg, D-22529 Hamburg, Germany)

The circulation of the North Atlantic ocean plays an important role in the global heat and mass transport. The current system is strongly connected to variations in the sea surface height (SSH) which can be measured by satellite altimetry. In the present study we investigate the mesoscale signals in the region from 20° N to 65° N and from 0° to 82° E using SSH measurements made by the TOPEX/POSEIDON altimeter. Starting from along-track calculated SSH anomalies we compute the amplitudes and phases of the annual and semi-annual cycle and show that even on small spatial scales the amplitudes can differ by as much as 4 cm. The statistical quantities like RMS values and eddy kinetic energy clearly represent the structure of the North Atlantic current system and also variations of the SSH due to topographic features can be made out. In order to detect interannual trends we have performed these calculations for the entire period of the years 1993-95 as well as for annual time intervals. We can distinguish different areas where the SSH is rising or falling. The most pronounced signal during this period is a rise of about 5 cm of the SSH in the eastern part of the subtropical gyre.

MESOSCALE VARIABILITY AND WIND FORCING

V. Garnier and R. Schopp (Laboratoire de Physique des Océans, B.P. 809, 29285 Brest cedex, France)

The sea level anomaly of the North Atlantic has been described during the period from January 1993 to April 1995. The study is focused on the mesoscale regions that are linked to the major currents: the Gulf Stream, the No rth-Atlantic Current and the Azores Current. Their intensity and stretch change with time. The spacially averaged variability increases during the winter and su mmer. Which for ve 54°N, the wind effect is immediate. A physical interpretation is su ggested: the stretch, intensity and position of the strong mesoscale activity ar eas should be linked to a simple condition of a baroclinic long Rossby wave stop ped by a mean e baroclinic instability.

ASSIMILATION OF SATELLITE ALTIMETRY WITH NORTH ATLANTIC CLIMATOLOGICAL HYDROGRAPHY

S. M. Grey and K. Haines (Department of Meteorology, University of Edinburgh Edinburgh, UK EH9 3JZ)

A method originally designed for assimilating satellite altimetry into general circulation models has now been applied to a climatological hydrography of the North Atlantic. The scheme assumes that sea surface height is not correlated with deep pressure variations and height anomalies are assimilated by a conservative vertical displacement of the thermocline.

Using Topex/Poseidon and ERS-1 altimetry, this method has been applied to climatological hydrographies of the North Atlantic from Levitus (1994) and Lozier *et al* (1995) to produce new hydrographic fields. Comparisons with *in situ* expendable bathythermograph data are reported. Improved currents can also be calculated geostrophically. It is hoped that, by this simple method, a better than climatological estimate of the sub-surface structure and currents can be attained based on satellite data.

ASSIMILATION OF ALTIMETER DATA IN A GLOBAL OCEAN MODEL

A. D. Fox and K. Haines (Department of Meteorology, University of Edinburgh, JCMB, King's Buildings, Edinburgh, EH9 3JZ, U.K.)
B. de Cuevas (James Rennell Division, Southampton Oceanography Centre, European Way, Southampton, SO14 3ZH, U.K.)

A method for the assimilation of altimeter data into free surface primitive equation ocean models which conserves water-mass properties is presented. This method is implemented for the first time in a global ocean model (OCCAM). Results from a twin experiment are shown, where surface height fields from a previous model run have been assimilated, allowing the degree of convergence of the assimilation run towards this model 'truth' to be tested. New surface height fields were assimilated at 15 day intervals. Assimilation is seen to have produced significant improvement of all model variables, with global RMS temperature errors reduced by 50%, salinity errors by 40% and velocity errors by more than 60% after running for 135 days. The results are examined in specific geographical regions to assess the relative performance of the method in different flow regimes. Convergence is found to occur fastest in mid-latitudes, where the assumptions of stratified water, and no change in near-bed velocities form good approximations. Convergence occurs more slowly in tropical regions, where horizontal advection of tracers is important in defining the vertical structure, and in the Southern Ocean, where stratification is weaker and barotropic currents are stronger. Finally, early results of assimilation of TOPEX/POSEIDON sea surface height anomaly maps into the model are shown.

ALTIMETRIC ASSIMILATION INTO A MESO-SCALE PRIMITIVE EQUATION MODEL OF THE AZORES-MADEIRA REGION.

M. Gavart (SHOM/CMO, Toulouse, France)
P. De Mey (UMR5566-GRGS, Toulouse, France)
G. Caniaux (Meteo-France/CNRM, Toulouse, France)

We present altimetric assimilation results in a primitive equation model over a 1000km square area in the Azores-Madeira region. The model has a fine horizontal and vertical grid mesh, a special open-boundary treatment and uses the TKE vertical mixing formulation. Surface atmospheric forcing is provided by ECMWF-model data. The model starts from initial conditions obtained by vertical extrapolation from altimetry using multivariate isopycnal EOFs and geostrophy (Gavart and De Mey, 1996). The experiments consist in 6 months of simulation, from 1993/06/03 to 1993/12/01 overlapping the SEMAPHORE experiment period (Eymard et al., 1996). The assimilation method is based on optimal interpolation and two different ways of projecting the surface error are considered: the dynamical method of Cooper and Haines (1996) and the projection along the Azores Current EOF. In both cases, the assimilation considerably reduces the misfit between surface model forecasts and satellite observations, and the results compare well with independent in situ measurements from the cruise. We discuss the differences between the two methods and the role of atmospheric forcings.

EXPERIMENTAL STUDY OF THE INTERACTION BETWEEN AN EXTERNAL SOLITARY WAVE AND SHORT SURFACE MONOCHROMATIC WAVES

K. Guizien and E. Barthélémy (Laboratoire des Ecoulements Géophysiques et Industriels, BP 53, 38041 Grenoble Cedex 9, France)

Long internal waves generate signatures on SAR images of the sea surface by modulating the surface wave field. Up to now mainly internal wave characteristic length and phase velocities are extracted from these images. We suggest on an experimental basis that by analysing more precisely the surface wave field, information on the amplitude of the internal waves could also be retrieved.

We describe experiments performed in a 36 m long and 0.5 m wide wave flume to study solitary-short surface wave interaction. Two type of experiments are carried out : short monochromatic waves i n the 1 Hz to 3 Hz range are either propagating in the same direction (strong interaction) or in the opposite one (weak interaction) with respect to the solitary wave propagation. The experimental data consist of free surface elevation at one location versus time.

The surface wave part before the arrival of the solitary wave is phase shifted compared to the part after it. The dependancy of this phase shift with the solitary wave amplitude and the short wave frequency is examined. We show that strong interactions lead to much larger phase shifts than weak ones. The experimental data is also discussed by comparison with analytical models.

This study is supported by the E.C. under MAST III MORSE project : Mesoscale Ocean Radar Signature Experiments (N° MAS3-CT95-0027 DG12 ESCY).

REMOTE SENSING OF THE PHYSICAL AND BIOLOGICAL VARIABILITY OF THE EASTERN ALBORAN SEA

T. H. Guymer, J. T. Allen, P. Cipollini, G. Corsini, T. N. Forrester, H. M. Snaith, S. Fielding, J. N. Schwarz, D. A. Smeed, S. G. Alderson and P. G. Challenor

The Alboran Sea is composed of a number of gyres in which warm fresh water from the Atlantic overlies relatively cool, saline water formed within the Mediterranean. At the eastern end the Almeria-Oran Front, a dominant climatological feature, separates Atlantic Water from the Mediterranean water. At the front itself upwelling of transitional water takes place and biological activity is enhanced. A combined in situ and satellite measurement programme, OMEGA, to study the front took place during October to December 1996 involving two ships, an aircraft and the use of several satellites equipped with visible, IR and microwave sensors. The combined in situ and remotely sensed datasets have enabled a detailed description of the surface water types, the fronts that separate them, the bio-optical properties, and the associated changes around the time of the cruise. Shipborne measurements indicate that the surface signatures visible from remote sensed data are indicative of circulation to a depth of more than one hundred metres. The results of the merging and interpretation of such a comprehensive dataset are discussed in detail. They show the potential and capabilities of the combined satellite/in situ approach in rendering a picture of the relationship between the physics of the front and bio-optical variability at the mesoscale with an unprecedented degree of accuracy. Particular attention is given to the relationship of the observed biological variability to the 3-D circulation at the front and to assessing the influence of sub-surface patchiness in the interpretation of ocean colour data from satellites. Longer term monitoring of the dynamics of the Almeria-Oran Front should now be possible by the combination of the altimeter, SeaSoar and ADCP data to determine the cross-track surface geostrophic current over the lifetime of the ERS satellites.

The Mediterranean Pathfinder SST dataset: from the statistical analysis to the boundary condition in Mediterranean OGCM

Daniele Iudicone, Istituto di Fisica dell'Atmosfera, CNR, Roma, Italy
Fabrizio D'Ortenzio, Istituto di Fisica dell'Atmosfera, CNR, Roma, Italy
Volfango Rupolo, ENEA Centro Ricerche Casaccia,Rome,Italy
Salvatore Marullo, ENEA Centro Ricerche Casaccia,Rome,Italy
Vincenzo Artale, ENEA Centro Ricerche Casaccia,Rome,Italy

The new Pathfinder SST dataset has been used to study the seasonal and interannual variability of the temperature field in the Mediterranean sea. The Pathfider data set consists of 12 hours maps at 9 km resolution for the entire world ocean. The data relative to the Mediterranean basin were extracted and two (day and night) objective maps per day were produced in order to fill the data gaps due to the cloud cover. These data were used to evaluate the time and space scales of the SST field and to follow the time evolution of some particularly interesting features like Iera -Petra anticyclone. EOF analysis was performed in order to evaluate the relative importance of the seasonal and interannual variability of the temperature field and mesoscale variability. The same data were used as surface boundary conditions for a derived Cox model of the Mediterranean sea. The model has a horizontal resolution of .25 degrees, 19 vertical levels and a buffer zone for the Atlantic region. We discuss some preliminary results from the comparison between the model runs using SST b.c. and those using climatological ones.

GENERALIZED INVERSION OF SATELLITE CHLOROPHYLL DATA FOR THE PRIMARY PRODUCTION IN THE NORTH ATLANTIC USING A FOUR-COMPONENT ECOSYSTEM MODEL

S.N Losa (P.P. Shirshov Institute of Oceanology Russian Academy of Sciences St. Petersburg Branch, Pervaya Liniya. 30, 199053 St. Petersburg,Russia)

A technique of parameter estimation by solving the generalized inversion of an ecosystem model for the ocean upper mixed layer was applied to assess the primary production (PP) in the deep North Atlantic. The model used describes the budget of phytoplankton, zooplankton, detritus, and nitrate and was constrained by mean monthly CZCS chlorophyll data. Model inputs optimized in the study were phytoplankton maximum growth rate, initial slop of P-I curve, phytoplankton and zooplankton maximum specific mortality rates, maximum rate and half-saturation constant of zooplankton ingestion. Estimates of the annual primary production obtained are in agreement with those of S. Sathyendranath et al.(1995). Namely, the spatial distribution of PP demonstrate strong variations in the latitude with maximum values located in the vicinity of the Atlantic coast of the Great Britain. Assessments of phytoplankton maximum growth rate have also a noticeable decrease in the southward direction.

ANNUAL VARIATION OF SEA SURFACE ELEVATIONS AND CURRENTS OVER THE SCOTIAN SHELF AND THE GRAND BANKS FROM THE TOPEX/POSEIDON ALTIMETRY

G. Han and P. C. Smith (Coastal Ocean Sciences, Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2, Canada)

The TOPEX/POSEIDON (T/P) altimeter data over the period 1992-96 have been analyzed to examine annual variability of the sea surface elevations and currents over the Scotian Shelf and the Grand Banks. A regional tidal model is employed to remove the oceanic tides from the altimetric sea surface elevations over these regions. To derive the annual cycle, harmonic analysis is applied to the time series of the sea surface elevations. The along-track sea surface slopes, which represent surface geostrophic currents, are also estimated along the T/P ascending and descending ground tracks. The altimetric results are compared with the solutions from a numerical model forced by baroclinicity, wind stress, and remote forcing. The comparison between the altimetric and modelled results indicates that the altimetric sea surface elevation variability is dominated by the baroclinic (and associated barotropic) component and supplemented by the wind-driven and remote-forced components. The altimetric elevations at Halifax and St. John's (interpolated from nearby T/P observations) agree favourably with the tide-gauge data, with an annual amplitude of about 5 cm high in late fall and low in late spring. The wintertime intensification of the shelf-break flows are suggested by the altimetric surface currents, consistent with the model solutions.

LARGE SCALE SEASONAL VARIATIONS OF ATLANTIC OCEAN BY COMBINING ALTIMETRIC AND HYDROGRAPHIC DATA IN AN INVERSE MODEL.

G. Larnicol (C.L.S. Space Oceanography Group, 18 Avenue Edouard Belin, 31055 Toulouse, France).

The response of Atlantic ocean from seasonal atmospheric forcing is observed by combining, in an inverse model, 3 years of Topex-Poseidon GDR (T/P), 1993 to 1995, with a climatology built from NODC data. The first step has consisted to observe and to analyse seasonal large scale signals over the whole atlantic, as steric effect, and variation of surface circulation from sea level anomalies (SLA). Seasonal cycle is clearly seen in the tropics even though oceanic signal seems to be dominated by steric effect in mid-latitudes. For steric effect, a relatively good accordance is obtained between the estimation provided by ECMWF net heat flux and T/P estimation. The second step is dedicated to the combination of hydrographic and altimetric data. An inverse model is developped here to give seasonal results. Altimetry is used to constrain the seasonal surface topography, especialy at large scales, where the precision is better. Results of the inverse model provide various seasonals maps of each term contained in the heat balance equation, as advection, net heat flux (given by ECMWF field), and heat content. An attempt is made to quantify the spatial distribution of those terms.

GLOBAL OCEAN DATA ASSIMILATION OF TEMPERATURE PROFILES: SENSITIVITY TO DATA COVERAGE

S. Masina, K. Miyakoda, A. Navarra, N. Pinardi and E. Masetti (IMGA-CNR, Via Emilia Est 770, 41100, MODENA, Italy)

The Derber and Rosati (1989) Optimal Interpolation scheme has been used to assimilate the latest World Ocean Atlas data set of Levitus (1994) for temperature vertical profiles. The data set is of unprecedented coverage in both hemispheres and we present a reanalysis of the assimilated temperature structure of the ocean after Rosati et al. (1995). The study period is 6 years starting from January 1987 ending december 1992 to partially overlap with Topex/Poseidon data wich will be used to validate the analyses produced only with temperature assimilation. The model is a global version of MOM at approximately 1x1 degrees of resolution and 1/3x1/3 degrees at the equator. Twice daily atmospheric analyses are used to force the model. Experiments are carried out with decreased amount of input data and the sensitivity of the analysis to the amount of data available is assessed. The tropical Pacific variability is discussed in detail with a comparison between simulations and assimilation runs.

OSCILLATION PATTERNS OF SEA SURFACE HEIGHT IN THE TROPICAL PACIFIC

A. Pauluhn (Institut für Meereskunde, Universität Hamburg, D-22529 Hamburg, Germany)

Climatic phenomena like El Niño are strongly influenced by the variability of the tropical Pacific ocean. Three years of TOPEX/POSEIDON altimeter sea surface height (SSH) data have been used to investigate the dominant oscillation modes in this area. The variabilities inherent in the observed SSH fields are studied using standard Fourier analysis as well as the method of empirical orthogonal functions (EOFs) and principal oscillation patterns (POPs). POPs are especially suitable for the detection of spatial patterns. Apart from the annual and semi-annual cycle, the predominant patterns of the SSH variability are given by the equatorial current system and by propagation of equatorial Kelvin and Rossby waves. Part of the variability of the SSH can also be ascribed to variation of the equatorial wind field. This has been found by comparison of the SSH oscillation patterns with oscillation patterns computed from the corresponding wind fields as provided by the European Centre for Medium-Range Weather Forecast (ECMWF). It is also shown that the altimetrically observed oscillation patterns of the SSH agree quite well with oscillation patterns calculated from SSH fields obtained from an ocean circulation model, the Hamburg Ocean Primitive Equation model (HOPE, Max-Planck-Institut für Meteorologie Hamburg).

STERIC SEA-LEVEL VARIATIONS IN A GLOBAL LOW-RESOLUTION OCEAN MODEL IN AN ASSIMILATION PERSPECTIVE

P. Rogel (CERFACS, 42 Av Coriolis, 31057 TOULOUSE Cedex, France)

The advent of Topex/Poseidon altimetry has evidenced sea-level variations to be dominated by steric variations at the larger scales. As most assimilation techniques have been designed for the mesoscale, where steric variations may be neglected, altimeter data assimilation into coarse resolution ocean models has to deal with this signal.
In this study, results from a 14-year forced global low-resolution run are used to compute straightforward steric sea level variations. The study discriminates steric contributions of upper and deep waters, and of haline and thermal variations. Both the mean seasonal signal and interannual variability are analysed. The upper ocean (200 m) heat content can explain more than 80% of the variance of the mean seasonal signal almost in all regions, except in the high latitudes where deep mixed layer develops during the winter. Salinity contribution is found small and its geographical distribution seems noisy, probably due to a damping term to Levitus climatology. Interannual variations are also dominated by thermal effects in the upper layers, but to a lesser extent, suggesting that deep changes in the density field are involved. After correcting for steric variations, the remaining sea level signal is weak and strongly correlated to the barotropic stream function signal.
Finally, a strategy for assimilating altimeter data into global models is presented in the framework of the AGORA project.

Relationship between Mediterranean Sea level anomalies from ERS and TOPEX/POSEIDON and subsurface sea structure from LIWEX and ERS-SYMPLEX experiments

Rosalia Santoleri,Istituto di Fisica dell'Atmosfera, CNR, Roma, Italy
Bruno Buongiorno Nardelli, Istituto di Fisica dell'Atmosfera, CNR, Roma, Italy
Daniele Iudicone, Istituto di Fisica dell'Atmosfera, CNR, Roma, Italy
Salvatore Marullo,ENEA Centro Ricerche Casaccia,Rome,Italy
Simona Zoffoli, Istituto di Fisica dell'Atmosfera, CNR, Roma, Italy

LIWEX and ERS-SYMPLEX data have been used to verify the performance of ERS and TOPEX/POSEIDON altimeters in the Mediterranean Sea. LIWEX experiment has been done during Winter-Spring 1995 in the Levantine basin to study the Levantine Intermediate Water formation and spreading. Although LIWEX experiment has been not designed for altimeters validation activity, the hydrographic data collected during this experiment firstly suggested the good correlation between dynamical height and Sea Level Anomalies in the Mediterranean Sea The ERS-SYMPLEX experiment has been carried out in the Sicily Channel during April-May 1996 to compare Sea Level Anomalies obtained form ERS-1/2 and TOPEX/POSEIDON altimeters with in situ data. During the cruise XBT and CTD casts have been densely done (about each 5 km) along all ERS-1/2 and TOPEX/POSEIDON tracks at the same time of each satellite pass. Measurements along satellite tracks have been repeated in order to relate differences between sea level measured by two altimeter passes and differences between dynamic heights derived from two corresponding hydrographic sections. Dynamic height have been calculated from CTD data and from XBT profiles, using T-S characteristics obtained by the CTD casts. The result of the comparison is very satisfactory and confirms the capability of the two altimeters to correctly detect both basin and mesoscale features of the Mediterranean circulation.

ON THE ASSIMILATION OF LARGE SCALE ALTIMETER DATA INTO PE MODELS

Jens Schröter (Alfred-Wegener-Institut für Polar und Meereskunde, Germany, e-mail: jgs@awi-bremerhaven.de)
Jörg Wolff (Antarctic CRC, University of Tasmania, GPO Box 252-80, Hobart, TAS 7001, Australia, e-mail: wolff@antcrc.utas.edu.au)

We investigate different techniques of assimilating large scale altimeter data into the barotropic mode of a primitive equation ocean model. TOPEX/Poseidon data are first expanded in spherical harmonics of low degree and order. Subsequently they are assimilated into a version of the Hamburg Ocean Primitive Equation model (HOPE) which covers the the southern hemisphere.
Three different techniques are tested for their ability to constrain the barotropic circulation. The first one is nudging of the models sea surface height. The second method consists of a least squares fit to the models barotropic dynamics and the observational data involving pre-defined structurs. The third method uses a representer technique. A comparison of the methods is performed that takes into account their respective convergence properties and their inpact on the barotropic ocean circulation.

PRELIMINAR RESULTS FROM THE LARGE SCALE CIRCULATION IN SOUTH INDIAN OCEAN USING AN INVERSE MODEL

E. Sultan (Laboratoire d'Oceanographie Physique du Museum National d'Histoire Naturelle, 43 rue cuvier 75231 Paris, France)

A Large Scale Circulation Sheme of the South Indian Ocean between 20E and 120E is to be proposed, simulated by a nonlinear finite-difference inverse model with both hydrology and altimetry from Topex/Poseidon.
The inverse model grid has a 2-degree resolution in latitude and 5-degree in longitude. It is based on hydrology and is in geostrophic and hydrostatic balances. Constraints of inverse model are Ekman pumping derived from ERS-1 wind data, conservations of mass, heat and salt, and the planetary vorticity equation at the reference level. The dynamic height deduced from altimetry is added as a constraint of the model.
For the first experiment, only the deepest historical hydrological stations are considered. This data set is objectively interpolated on the model grid after an EOF decomposition on the vertical.

Reconstruction of the Word Ocean Large-Scale Circulation From the Sea Surface Height Data

A. Yaremchuk (Andreyev Acoustics Institute, Shvernika 4, 117036 Moscow, Russia)

J. Schröter (Alfred-Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany)

We propose and apply a method for reconstruction of the barotropic constituent of the global oceanic circulation from the large-scale dynamic sea surface topography. Mean large-scale currents are composed from low-frequency eigenmodes of the linear shallow water equations on geoid with the best fit to collected data in the least squares sense. Our major aim is development of a finite element hydrodynamic model and observation operator, spectral analysis of data with respect to the ability of its representation by the dynamical model, and solution of the inverse problem. Preliminary processing of TOPEX/POSEIDON altimeter data is done.

Decadal SSH variations in multi-satellite altimeter data and in the Hamburg LSG model

Jiansheng Zou and Jens Schröter (Alfred-Wegener-Institute for Polar and Marine Research, Am Handelshafen 12, 27515 Bremerhaven, Germany)

Monthly sea surface height (SSH) variations from multi-satellite altimeter data (GEOSAT, ERS-1 and Topex/Poseidon) were combined to generate consistent SSH variations over the periods of these satellite missions. Corresponding SSH fields from 1980 to 1994 were derived from a global ocean circulation model - the Hamburg Large Scale Geostrophy (LSG) model. A comparison between these two data sets was first carried out regarding the phases and strengths of salient climatological events, e.g. El Niño and La Niña events during 1986-1988 and during 1992-1994. A variety of statistical analysis tools, e.g. empirical orthogonal functions, principal oscillation patterns, canonical correlations, were also used to describe and compare these two data sets.

Lately, multi-satellite altimetric SSH data were assimilated into the barotropic part of the LSG model using a least squares fit. Emphasis is placed on whether using altimeter data alone can yield satisfactory result or whether other data are necessary.

G7 Geoapplications of satellite altimetry

Convener: Klokocnik, J.
Co-Conveners: Moore, P.; Wagner, C.A.

GLOBAL GRAVITY FIELD FROM THE ERS-1 AND THE GEOSAT GEODETIC MISSION ALTIMETRY

Ole Baltazar Andersen and Per Knudsen (Kort & Matrikelstyrelsen, Rentemestervej 8, 2400 Copenhagen NV. Denmark,
E-mail: oa@kms.min.dk, pk@kms.min.dk)

Altimeter data from the entire ERS-1 and the GEOSAT Geodetic Missions have been used in an evaluation of the Earth gravity field. The processing of the altimetry has been improved with respect to the editing of the data and the filtering of the resulting anomalies. Initially, a cross-over adjustment was carried out using bias, tilt, and curvature terms. Then gross errors and outliers were detected by comparing the data with estimated values obtained using collocation. Subsequently, the altimetry was crossover adjusted and fitted to the OSU91A geoid model. The adjusted sea surface heights were gridded using local collocation in which residual ocean variability was eliminated. The conversion of the heights into gravity anomalies was carried out using FFT. Through this process a filtering was performed in the spectral domain. The gravity field has been mapped world wide with a resolution of 3'45" by 3'45" corresponding to seven by seven kilometres at the Equator. The map displays the tectonic structures under the oceans as well as changes in the bathymetry. Large plate boundaries are clearly displayed, such as: The spreading zones in the Mid Atlantic and Indian Oceans and the subduction zones around the Pacific Ocean.

GRAVITY FIELD DETERMINATION FROM THE COMBINED ALTIMETRY DATA SETS OF ERS-1 AND TOPEX/POSEIDON BY SIMULTANEOUS ORBIT ADJUSTMENT

H.J. Boomkamp (Aston University, Birmingham)

The orbits of ERS-1 and TOPEX/Poseidon can be solved simultaneously, using dual satellite crossovers to globally correlate the two orbits. The geographically correlated radial orbit error is different for the two satellites, which means that the entire radial orbit perturbation is present in the dual crossover data. Simultaneous solutions for ERS-1 and TOPEX/Poseidon will therefore help to decouple the radial perturbation from the geoid height error in the altimetry data sets. A gravity field model is presented based on a period of 7 cycles for TOPEX/Poseidon, solved simultaneously with 2 multidisciplinary 35-day cycles for ERS-1. Included data sets are the altimetry and SLR data from both satellites, DORIS data for TOPEX/Poseidon, and the dual crossover data. The JGM-3 covariance matrix is used to constrain the solution.

ORBIT ERRORS AND DATUM DIFFERENCES ESTIMATED SIMULTANEOUSLY FROM MULTI-MISSION ALTIMETRY

W.Bosch, (DGFI, Abt. I, Marstallplatz 8, D-80539 München, Germany)
C. Wagner (NOAA/NOS, 1305 East-West Highway, Silver Spring, MD 20910, USA)
J. Klokocnik (Astronomical Inst. CZ-251 65 Ondrejov, Czech Republic)

Kaula's first order theory expresses the orbit error as function of increments to the gravity field harmonics. Altimetric crossover differences, "observed" as difference between the sea surface heights of two crossing arcs carry the signature of gravitational orbit errors. Therefore they can be used to estimate gravity field corrections that in turn allow to correct the radial orbit component.
Crossover differences exhibit, however, also geographical pattern that are inconsistent with orbit dynamics. Due to different tracking systems or an inconsistent pole position reference, small datum differences between pairs of satellites must be considered. They transform to increments of the so called "forbidden" harmonics: the degree 1 and the degree 2, order 1 coefficients.
In the present paper we use crossover differences from Geosat, ERS-1 and Topex/Poseidon altimetry and solve for the first time simultaneously for i) corrections to gravity field harmonics and ii) a few additional parameters that account for datum differences relative to Topex/Poseidon (assumed to have the most reliable tracking). The paper investigates in particular the capability to decorrelate datum parameters and low degree and order harmonics.

SEPARATION BETWEEN MEAN SEA LEVEL AND GEOID IN EUROPEAN SEAS

L. Fenoglio-Marc and E. Groten (Institute of Physical Geodesy, Technical University, Petersenstrasse 13, D-64287 Darmstadt, Germany)

The separation between the mean sea level and the mean geoid, the mean sea surface topography, is investigated in European seas. It is computed using two different methods: as difference between an altimetric mean sea level and a locally improved gravimetric geoid and from oceanographic methods. Results at the coastal boundaries are less accurate than in the open sea, due to the decrease in the accuracy of the altimetry data and of the hydrodynamic models in shelf areas. The analysis at the coastal boundary is important, in geodesy, to investigate the height differences between the national vertical datums in Europe. The results depend on the accuracy of the altimetry data and of the gravimetric information. The differences between the altimetric-gravimetric sea surface topography and the oceanographic mean sea surface topography are mainly due to errors in the geoid. In this study, data of the ERS-1 and ERS-2 35-day repeat missions and the corresponding Topex/Poseidon data are used. Previous results, obtained with smaller amount of data, are confirmed. More accurate results are obtained.

INVESTIGATING THE BEHAVIOUR OF THE SEA STATE BIAS WITH NON-PARAMETRIC ESTIMATION METHODS

J.P. Florens (Université des Sciences Sociales, Place Anatole France, 31042 Toulouse Cedex)
P. Gaspar (C.L.S. Space Oceanography Division, 18 Avenue Edouard Belin, 31401 Toulouse Cedex 4, France).

Theoretical understanding of the sea state bias (SSB) is still too limited to provide directly usable models. Empirical parametric models are thus used to estimate, and correct for, this effect. It has been previously noted that the parametric formulation might overly constrain the simulated variations of the SSB. To avoid this we reformulate the SSB estimation problem in a way that is appropriate for use of non-parametric methods. Here we use the Kernel estimation technique to obtain fully non-parametric estimates of the SSB as a function of both wave height and wind speed. Estimated SSBs for both TOPEX and POSEIDON are presented. They exhibit similar behaviours. The results are also compared with previously obtained parametric estimates and the differences are analysed.

A MEAN SEA SURFACE DEDICATED TO MERGED SATELLITE STUDIES IN OCEANOGRAPHY.

F.Hernandez (C.L.S. Space Oceanography Division, 18 Avenue Edouard Belin, 31401 Toulouse, France).
P. Bahurel (SHOM/CMO, GRGS/BRESM, 14 Avenue Edouard Belin 31400 Toulouse, France).

Topex/Poseidon (T/P), GEOSAT, ERS-1 and ERS-2 improved altimetric dataset are available for studying the ocean variability. Merging of these data can be obtained using a common sea surface reference (mean sea surface MSS). We are presenting here a MSS dedicated to oceanography, focusing on the accuracy of the mean sea height along the satellite ground tracks. We use a T/P, ERS and GEOSAT repeat track data, and the 2 ERS-1 168-day-geodetic cycles, providing higher spatial resolution. ERS and GEOSAT profiles are referenced to the T/P mean profile (the most accurate) by a spline adjustment (Le Traon, et al., 1996). This technique also reduces orbit errors. In order to remove the ocean variability, we subtract the sea level anomaly (SLA) to the instantaneous sea surface height (SSH). The SLA along the ERS tracks is estimated by optimal interpolation of T/P data. Thus, ERS crossover rms differences are lowered from 13-15 cm to 10 cm, and we obtain mean sea height from SSH with a precision of 7 cm. Moreover, the calculated ERS mean profile is 2 cm accurate (T/P's one is 1.2 cm accurate). The MSS is calculated by suboptimal estimation (i.e. inversion) where along track residual large scale errors are reduced. A first estimate of the MSS is compared in the North-East Atlantic to other MSS. Discrepancies are relative to the interannual oceanic signal and along track accuracy of the altimetric data used.

PROJECTION OF EGM 96 COVARIANCE MATRIX TO CROSS-OVER AND LATITUDE LUMPED COEFFICIENT ERROR

J.Klokočník (Astronom. Inst. Czech Acad. Sci., CZ-251 65 Ondřejov Obs.; jklokocn@asu.cas.cz)
F. G. Lemoine (Laboratory for Terrestrial Physics; NASA GSFC, Greenbelt, Maryland 20771 USA; flemoine@olympus.gsfc.nasa.gov)
J.Kostelecký (Research Institute for Geodesy, CZ-250 66, Zdiby 98; vugtk@ms.anet.cz)

Using the procedure described by Klokočník et al. [1996], the calibrated variance-covariance matrix of harmonic geopotential coefficients of the new EGM 96 gravity model (to 70x70) will be projected to single- and dual- satellite crossover errors, and latitude lumped coefficient errors. These results will be compared with previous gravity solutions, such as JGM 2 and JGM 3, to assess the strengths and weaknesses of the new solution. This analysis will quantify the level of improvement over previous solutions, as well as suggest areas where further refinements are required.

IMPROVED RECOVERY OF THE GLOBAL MARINE GRAVITY FIELD FROM THE GEOSAT AND THE ERS-1 GEODETIC MISSION ALTIMETRY

Per Knudsen and Ole Baltazar Andersen (Kort & Matrikelstyrelsen, Rentemestervej 8, 2400 Copenhagen NV. Denmark,
E-mail: pk@kms.min.dk, oa@kms.min.dk)

Satellite altimetry from the GEOSAT and the ERS-1 Geodetic Mission provides altimeter data with a very dense coverage. Hence, the gravity field may be recovered very detailed. However, since neighbouring ground tracks are located very closely, cross track variations in the sea surface heights are extremely sensible to sea surface variability. In order to avoid errors in the gravity field caused by such effects, sea surface variability need to be carefully eliminated from the observations. Initially, a crossover adjustment was carried out using bias and tilt terms. Then gross errors and outliers were detected by comparing the data with estimated values obtained using collocation. Subsequently, the altimetry was crossover re-adjusted. The re-adjusted sea surface heights were gridded using local collocation in which residual ocean variability was considered. The conversion of the heights into gravity anomalies was carried out using FFT. Through this process a filtering was performed in the spectral domain in order to avoid the so-called "orange skin" characteristics. Using both ERS-1 and GEOSAT altimetry the fine tuning of the method is described.

CALIBRATION METHODS FOR THE TOPEX AND POSEIDON ALTIMETRY SYSTEMS

D. G. Kubitschek, G. H. Born and K. W. Key (Colorado Center for Astrodynamics Research, University of Colorado at Boulder)
B. J. Haines (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California)
S. K. Gill (NOAA/National Ocean Service, Ocean and Lake Levels Division, Silverspring, Maryland)

Several methods of calibrating the TOPEX and Poseidon altimeters have been developed and employed. Platform Harvest serves as the primary calibration site where instrumentation has been installed and sea level estimates, which are determined from the CU sea level system and from the NOAA acoustic system, are used in the closure analysis. Recent results have shown the TOPEX bias to be -1 ± 8 mm using the CU system and 4 ± 7 mm using the NOAA acoustic data. Bias dri ft estimates have been determined to be 4 ± 4 mm/yr using the CU system and 2 ± 4 mm/yr using the NOAA system. The same analysis is performed for the Poseidon altimeter. Bias and bias drift estimates are determined to be 18 ± 8 mm and 4 ± 4 mm/yr, respectively, using the CU system. Results from the water vapor radiometer located at Harvest show a drift in the TOPEX microwave radiometer of -1.9 ± 1.2 mm/yr using all available overflight data. In addition to the primary calibration eff ort a GPS equipped buoy has been deployed near platform Harvest for the purpose of calibration. Results indicate that differences between the Harvest tide gauges and the GPS buoy derived sea level estimates never exceed 1.5 cm.

EVALUATION OF THE GEOIK AND GEOSAT ALTIMETER SYSTEMS OVER BLACK AND CASPIAN SEAS

A. P. Medvedev (Space Research Institute, Profsoyuznaya 84/32, 117810, Moscow, Russia; radiom@mx.iki.rssi.ru)
S. Lebedev (Geophysical Center, Molodezhnaya 3, 117296 Moscow, Russia)
P. P. Medvedev (Geophysical Center, Molodezhnaya 3, 117296 Moscow, Russia; pmedv@wdcb.rssi.ru)

Previously classified data from Russian GEOIK altimetry satellites from mid 1985 to 1995, is being transferred to the World Data Center. These Russian satellites were in near circular orbits at an altitude of about 1500 km. Most had an inclination of 74^0, but some had an inclination of 83^0. The altimeters operated at a frequency of 9.5 GHz. Geophysical Center RAS creates the Data base of the measurements with these satellites and US GEOSAT satellite also. The GEOIK data format is similar to the Geosat standard format. The contents of the Data base, data statistical analysis, an error budget and precision orbit determination for the GEOIK data are discussed. Precision of the GEOIK radar altimeter data (instrumental error, noise level) ranged from 0.5 to 0.8 m (1 sec averaging) in various spacecrafts. Signal processing can reduce this error. The GEOIK and GEOSAT altimeter data is evaluated for the 1985-1989 years using tracks over the Black and Caspian seas and other World ocean areas to estimate the heights of the seas surface. The possibilities of the use these data for the study mean sea level variations are discussed also. Comparisons with in-situ data are discussed also.

USE OF SATELLITE ALTIMETRY, GRAVIMETRIC GEOIDS, GPS AND PRECISE LEVELLINGS FOR UNIFICATION OF VERTICAL DATUMS

Markku Poutanen (Finnish Geodetic Institute, Geodeetinrinne 2, FIN-02430 Masala, Finland)

We present a compilation of two Baltic Sea Level GPS campaigns, together with satellite altimetry, gravimetric geoids, and precise levellings. The GPS observations were made at tide gauges around the Baltic Sea. We compare gravimetric geoid and altimetric geoid plus sea surface topography on the sea area and, additionally, use the GPS observations at the tide gauges. Based on this data we discuss the possible establishment of a unified vertical datum in the area of the Baltic Sea and its surroundings and also its connection to the EUVN campaign. A proper definition of a new regional vertical datum is made. We also give a connection between the proposed vertical datum and national height systems of Finland, Sweden, Estonia, Latvia, Lithuania and Poland using more than 100 points, including permanent GPS network points in Sweden and Finland. Formulae given allow transformation from a national height system to the common datum.

LASER ALTIMETRY FOR POLAR ICE SHEET MASS BALANCE, LAND TOPOGRAPHY, AND ATMOSPHERIC APPLICATIONS

B. E. Schutz (Center for Space Research, The University of Texas at Austin)

The Geoscience Laser Altimeter System (GLAS) is scheduled for launch in 2001–2002 as one of the NASA Earth Observing System platforms. The instrument uses a laser altimeter with a 70-m ground spot diameter to *(1)* enable study of polar ice sheet mass balance, *(2)* measure land topography profiles, and *(3)* provide along-track cloud and aerosol height distributions and planetary boundary layer height. The mapping of the polar ice sheets will be performed using a ground track with a 183-day repeat cycle, except for an initial verification phase which will use an 8-day repeat cycle. Laser pointing knowledge at the arcsecond level will be provided by star cameras. The instrument position will be determined to 5 cm radial and 20 cm horizontal using GPS and ground-based laser tracking. The initial verification phase will be used to tune the gravity field for the 600-km altitude satellite to enhance the orbit accuracy during the primary mapping phase. Ground-based instrumentation is being planned for instrument pointing and height measurement verification. Geodetic considerations of the mission will be highlighted, including the measurement error budgets. Simulations using crossover measurements as the primary data type for the tudy of temporal variations in the ice sheet will be described.

ON THE USE OF TIDE GAUGE DATA FOR CALIBRATING ERS AND TOPEX/POSEIDON ALTIMETRY

P. Moore, **S. Carnochan, S. Ehlers, C. M. Murphy** and **M. D. Reynolds** (Department of Civil Engineering, Aston University, Birmingham, B4 7ET, UK)

Altimetric satellites require continuous calibration if systematic trends are not to be aliased into studies of long term sea-surface variability and sea-level rise whilst tide gauge data provides the most abundant source of ground truth. Hence by augmenting altimetry with tide gauge data ocean variability can be removed enabling any spurious trends in the altimetric data to be identified. In this study tide gauge augmented crossovers from TOPEX/Poseidon and ERS-1 are investigated for residual trends with sea-level rise for 1992-6 recovered.

ALTIMETRIC GRAVITY ANOMALIES BASED ON GEOSAT AND ERS-1 GEODETIC PHASE DAT A

M. Rentsch, M. Anzenhofer, Th. Gruber and K.H. Neumayer (GeoForschungsZentrum Potsdam (GFZ), Division 1, D-PAF, P.O.Box 1116, D-82230 Oberpfaffenhofen, Germany, e-mail: adp@dfd.dlr.de)

The knowledge of a highly-accurate and detailed gravity field over the ocean serves as a basis for investigations of short-wavelength bathymetry features. High-resolution gravity anomalies are derived from reprocessed altimeter data of Geosat and ERS-1 geodetic missions. For ERS-1, GFZ/D-PAF has reprocessed the ESA standard altimeter product. This process includes improved orbit calculation, the replacement of standard geophysical corrections and the application of additional range corrections. Gravity anomalies are computed by means of Fast-Fourier transformation (FFT) from vertical deflections which are derived at each single altimeter measurement and converted to high-resolution 3'× 3' grids. The error due to the plane approximation of the earth is minimized by first subtracting a long wavelength spherical harmonic geoid model (e.g. degree 40) from the measured sea surface heights, before generating the vertical deflection grids. A piecewise application of the FFT approach combined with the elimination of the margins of each computation area suppresses truncation effects. After reconstruction of the original area the final result is obtained by adding back the long wavelength part to the computed residual gravity anomalies. Quality tests are performed by comparing the results of both altimeter missions with anomalies from the gravity map of *Smith & Sandwell* [1995] and shipboard data distributed by BGI Toulouse.

G8 The role of geodesy in the study of global change

Convener: Zerbini, S.
Co-Convener: Klosko, S.M.

THE ROLE OF GPS IN THE STUDY OF GLOBAL CHANGE

G. Beutler and M. Rothacher (Astronomical Institute, University of Berne, CH-3012 Berne, Switzerland)

GPS is the youngest of the three mature Space Techniques VLBI, SLR and GPS. Its contribution to global geodynamics was almost non-existent before 1990, it was dramatically improved by the creation of the International GPS Service for Geodynamics (IGS) in 1991.
Space Geodesy provides the Terrestrial (to a certain extent also the Celestial) Reference Frame for all studies related to Global Change. GPS is of vital interest in this context because it is THE technique for the densification of the ITRF (the International Terrestrial Reference Frame).
Height determinations are of particular importance for all studies related to Global Change. Highly accurate station heights are much more difficult to achieve than accurate horizontal positions with the GPS due to the following reasons: (a) there exist strong correlations between station heights and models for tropospheric refraction; (b) there are also strong correlations between troposphere effects and elevation (and azimuth) dependent antenna phase center variations; (c) there are correlations between station heights and orbit errors. Despite all these problems GPS, in cooperation with SLR and VLBI, is probably the best (and from the operational point of view the most efficient) tool to provide the reference frame for Global Change studies. We discuss the problems mentioned, give an overview of the state of affairs (in particular of the IGS and its project on the densification of the ITRF using the GPS), and conclude with an outlook over the future development.

REGIONAL AND GLOBAL SEA LEVEL CHANGE FROM SATELLITE ALTIMETRY

A. Cazenave, M.C. Gennero, K. Dominh and P. Schaeffer (GRGS-CNES, 18, Avenue Edouard Belin, 31401 Toulouse Cedex 4, France)

Sea level changes are important indicators of climatic variations. Absolute sea level measurements with high and homogeneous spatio-temporal coverage are now routinely performed by satellite altimetry. We have studied temporal changes in sea level at both regional and global scales, using altimeter data of Topex-Poseidon, ERS-1 and ERS-2 over an interval of time of ~ 4 years, focusing on the interannual signal. At regional scales, studied areas are the Mediterranean and Black seas, Caspian and Aral seas. In the Mediterranean sea, sea level exhibits a strong interannual variation, in particular since the end of 1995, which originates in the Levantine basin. In the Black sea, a mean sea level rise of ~ 23 mm/yr is observed over the 4-yr time span. Since 1978, the Caspian sea has been rising at an average rate of ~ 13 cm/yr. Altimeter data analysed between Dec. 1992 and July 1996 show an almost linear trend of the Caspian sea level of + 19 cm/yr. Since that date, a reversal has been initiated and is still seen in 1996. The dramatic sea level drop of the Aral sea is easily recorded by altimeter data. The observed water level decline is approaching 30 cm/yr over the 4-yr period and is even accelerating since mid-1995. We have also investigated the mean sea level change at a global scale as well as its geographical distribution. In all cases (global and regional), relationship between sea level change, sea surface temperature, and other meteorological parameters has been investigated. For the Caspian sea, change in river runoff and salinity is discussed in relation with the observed sea level change.

ABSOLUTE GRAVITY AND GPS MEASUREMENTS IN GREENLAND

T van Dam (NOAA/CIRES, Campus Box 216, University of Colorado, Boulder, CO 80309; ph. 303-492-5670; fax 303-492-1149; Internet: tonie@robeson.colorado.edu); J Wahr (Dept. of Physics/CIRES, Campus Box 390, Universtiy of Colorado, Boulder, CO 80309; ph. 303-492-8349; Internet: wahr@longo.colorado.edu); K Larson (Dept. of Aerospace Engineering Sciences, University of Colorado, Campus Box 429, Boulder, CO, 80309; ph. (303) 492-5141; e-mail: kristine.larson@colorado.edu); D Roberson and G Sasagawa, (NOAA-N/OES12 8600 North 39th Street, Longmont, CO 80503; ph. 303-497-7405; Internet: glenn@robeson.colorado.edu)

Changes in the distribution and volume of ice in Greenland or Antarctica could cause vertical crustal motion of up to a few mm/yr around the edges of those ice sheets. The viscoelastic response of the earth to past changes in ice loading could cause vertical motion rates that are several times larger than this. Thus, the visco-elastic effects must somehow be removed before the observations can be used to help constrain the mass balance of the ice caps. Models of the earth's visco-elastic response to surface loads, suggest that this can be done by combining vertical motion measurements with simultaneous observations of gravity. To apply these ideas, we have begun a multi-year, NASA-funded program to make simultaneous measurements of absolute gravity and crustal motion (using continuously-operating GPS receivers) in Greenland. The program was initiated in July, 1995, so that there are not yet enough data to allow us to constrain the mass balance of the ice sheet. In this talk, we will describe the project, and the theoretical results that motivate it.

Contribution of Long-term Satellite Laser Ranging to Earth Science
Richard Eanes (Center for Space Research, The University of Texas, Austin, Texas 78712, USA)
Laser ranging to near-Earth satellites was initiated by NASA in 1964 with the launch of BE-B geodetic satellite. Since then, satellite laser ranging (SLR) have evolved into a powerful tool for studies of Earth science including: the dynamics of the Earth-ocean-atmosphere-cryoshpere system, the establishment and maintenance of the terrestrial reference system, geocenter motion, polar motion and Earth rotation, Earth gravity field and its variations associated with astronomical causes and from climate and geophysical related phenomena, post-glacial rebound and core-mantle dynamics of the Earth, and the monitoring of crustal and tectonic motions. SLR has proven to be necessary for precision orbit determination of altimetric and geodetic satellites, and has been demonstrated to be critical in its use to calibrate other radiometric satellite tracking measurement systems, such as Doris, PRARE, and spaceborne GPS. SLR also represents the only absolute ranging measurement system available for satellite tracking and for Earth science studies. SLR ranging precision has improved from a few meters in the 1970s to several millimeters. Global SLR stations have grown from a few stations to a global network of 43 stations in more than 30 countries. More than 10 SLR-targets are currently flying, and they provide one of the longest geodetic time series (22 years, Starlette and Lageos-1 tracking) for geodynamic research. This paper provides a review of the SLR technique in studying various aspects of Earth science. In particular, phenomena in the form of time-varying gravity field which can beea observed from analysis of long-term SLR tracking data and are associated with mass redistribution of the Earth system will be discussed. These signals range from several hours to 18.6 years to geological time scale. Finally, this paper will provide a review for the contribution of long-term SLR tracking to studies of Earth science and natural hazards.

GEODETIC ICE SHEET ELEVATION MONITORING IN GREENLAND FOR GLOBAL CHANGE RESEARCH

R. Forsberg, K. Keller, S. Ekholm, C. S. Nielsen (KMS, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark)
C. C. Tscherning, N. Gundestrup (Geophysical Dept., Niels Bohr Institute, Univ. of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark)
S. N. Madsen (Danish Centre for Remote Sensing, DTU, DK-2800 Lyngby, Denmark).

Global changes in sea level may be indirectly studied through the monitoring of surface elevations of the polar continental ice sheets (Antarctica, Greenland), which act as the major source/sink areas of global water volume changes. This monitoring may be carried out by satellite altimetry, surface GPS surveys, airborne laser surveys and SAR interferometry. This paper presents early results from a Greenland elevation monitoring project (ECOGIS), evaluating accuracy of elevation determination techniques, as well as studying changes at select sites. At the centre of the ice sheet elevations have since 1992 been stable, with measured sinking rates being offset by equivalent accumulation of new snow, all in good agreement with glaciological flow models.

Shuttle Laser Altimeter Observations of Terrestrial Topography

J.B. Garvin, J.L. Bufton, J.B. Blair, D.J. Harding, J.A. Marshall
(NASA Goddard Space Flight Center, Greenbelt, MD, USA)
S.B. Luthcke, J.J. Frawley
(Hughes STX, Lanham, MD, USA)

In January of 1996, the maiden spaceflight of the Shuttle Laser Altimeter (SLA) experiment was successfully conducted as part of the STS-72 mission aboard the Shuttle Orbiter Endeavour. SLA was intended to serve as a pathfinder for future Earth-orbital and planetary mapping laser altimeter sensors by demonstrating the technologies and algorithms of "geodetic surface lidar". In addition, SLA's scientific objectives included: measurement of low-lying coastal areas which are severely susceptible to storm-surge flooding, and evaluation of the vertical structure ("roughness") of 100 m diameter patches of the Earth's surface by means of waveform digitization and analysis of the backscattered echoes acquired. Additionally, SLA's spaceflight was the first opportunity to evaluate the combination of Shuttle precision orbit determination and attitude corrections to facilitate geodetic-precision topographic measurements. During 80 hours of operation, SLA acquired over 1.4 million ocean and land surface observations, and nearly 1.2 million cloud top measurements. Preliminary analysis suggests that for ocean surfaces, ranging accuracies at the limit of the resolution of the SLA sensor have been achieved; i.e., less than 2 meters. Comparisons of SLA data with high resolution digital elevation models indicates 10 to 50 m RMS differences are typical. Spaceborne Laser Altimetry provides global monitoring of land, ocean, and cloud surfaces, and will be of significant importance to future global change studies.

Very Low Frequency Sea Level Change Observed by TOPEX/POSEIDON

R. S. Nerem, Center for Space Research, The University of Texas at Austin
G. T. Mitchum, Dept. of Marine Sciences, University of South Florida

Over the past four years, the TOPEX/POSEIDON (T/P) satellite altimeter mission has provided 10-day maps of sea level with a point-to-point precision of 2-3 cm. While this is a great achievement in itself, the long term stability of these measurements is even more remarkable, and it allows us to begin studying the very low frequency (VLF) components of sea level change. In particular, the long-term veracity of the measurements of global mean sea level now allow us to place bounds on the rate of sea level rise over the past four years. Studies of VLF sea level change require careful monitoring on the instrument behavior. In this regard, we have monitored the altimeter performance using comparisons to sea level measured simultaneously at island tide gauges. It has been demonstrated that the tide gauges can monitor the long-term stability of the altimeter to an accuracy of 1-2 mm/year. We will present the latest T/P measurements of changes in mean sea level in the context of the long term instrument behavior as measured by the tide gauges. These results will also include a discussion of the effects of the recently discovered error in the T/P oscillator correction, which largely accounted for the extreme rates of sea level rise previously observed in the T/P data. We will discuss the geographical characteristics of the VLF sea level change observed by T/P. We will also present maps of VLF changes in sea level, although these maps are currently dominated by interannual changes in sea level, such as the ENSO. With only a four year time series, it would be premature to interpret the T/P observations in terms of climate change. However, as a longer time series is accumulated, T/P will provide important corroboration of such predictions by climate models.

QUALITY INVESTIGATION OF VERTICAL HEIGHT DATUM CONNECTION

Kyra van Onselen and Martin van Gelderen (Delft Institute for Earth Oriented Space Research (DEOS), Delft University of Technology, P.O. Box 5030, NL - 2600 GA Delft)

For a global interpretation of sea-level as observed by tide gauges, vertical datums as used in different countries or continents need to be connected. The direct connection can be performed using space techniques such as GPS. This, however, gives only a connection in the sense of geometric heights. To connect orthometric heights the geoid is required. In this paper it is investigated, what quality might be expected from the connection of vertical datums, for a number of data configurations and based on measurements of varying accuracy. For a stylized global data configuration, results are compared for two potential coefficient models. A number of aspects of the datum connection problem is worked out in greater detail in a regional approach. In this regional approach, the quality of potential differences between the datum zones, based on state-of-the-art measurements, is in the order of 1 cm.

GEODETIC SIGNATURES OF GLOBAL GLACIAL ISOSTASY: IMPLICATIONS FOR THE UNDERSTANDING OF GLOBAL CHANGE

W.R. Peltier (Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7)

Of the broad spectrum of "slow" processes that constitute the background against which geodetic inferences of ongoing "rapid" global change must be made, the most important is arguably the global process of glacial isostatic adjustment. It has been most clearly demonstrated that this process continues to exert significant influence on three dimensional crustal motion, relative sea level and even on earth rotation. Especially significant, perhaps, is the contribution to sea level. The gravitationally self-consistent global theory of glacial isostatic adjustment is herein applied to predict the extent to which TOPEX/POSEIDON type altimetric measurements of sea level height might be contaminated in their average by the ongoing GIA process. Three dimensional crustal motions predicted by the theory will also be presented, based upon the model of the radial variation of viscosity recently inferred through formal inversion of the data (W.R. Peltier and Xianhua Jiang, J. Geophys. Res., 101, 3269-3290, 1996; W.R. Peltier and Xianhua Jiang, Geophys. Res. Lett., 23, 503-506, 1996; W.R. Peltier, Science, 273, 1359-1364, 1996). Based upon the crustal motion and geoid predictions, a variety of characteristic signatures of the global process emerge that may be employed to further refine the model. Of particular interest are those accessible to VLBI measurement and those which are more effectively observed using the Global Positioning System.

High resolution gravity measurements - an additional tool for the understanding of vertical movements

B. Richter, Institute for Applied Geodesy, Richard Strauss Allee 11, D-60598 Frankfurt am Main, Germany
I.Marson, DINMA, Univ. Trieste, Via A. Valerio 10, I-34127 Trieste, Italy

Any crustal process which involves a height variation has direct implication on the temporal variation of the gravity field, in terms of vertical movement of the measuring point and of mass or density redistribution in the vicinity of the measuring point as well as far field or global effects. Therefore gravity measurements can assist to verify vertical crustal deformation models and to contribute to the improvement of correction models which are nessecary to separe temporal vertical crustal movements induced by ocean, atmospheric and ground water loading effects from the long term processes. A specific experiment at Medicina / Italy will enable an assessment to be made of the accuracy with which vertical crustal movements can be determined. Within this experiment it is foreseen to monitor continuously not only the station position by a permanent GPS observations as well as by VLBI experiments but also the gravity field and environmental variables. For the gravity monitoring absolute gravimetry and stationary measurements with superconducting gravimeter are carried out. The state of the art for both techniques, first results from repeated absolute measurements and the analysis of 4 month continuous registration with a superconducting gravimeter will be discussed.

INTEGRATED GLOBAL GEODETIC OBSERVING SYSTEM AND THE ROLE OF THE GRAVITY FIELD

R. Rummel (Institut für Astron. & Physik. Geodäsie, TU München, Arcisstraße 21, D-80290 München, Germany)

In a very successful effort the international geodetic community has succeeded to realize a terrestrial and a celestial frame with greatest precision. Advanced kinematic monitoring techniques such as satellite altimetry (ocean & ice), INSAR, or groundbased GPS, provide insight into the temporal changes of the Earth's land surface, its ice cover and of the oceans, provided these techniques are rigidly tied into the terrestrial frame. Observation of variations in Earth rotation reflect the integrated effect of any change in angular momentum of the Earth system components. What can an improved knowledge of the Earth's gravity field add to an observing system of this kind: ocean surface circulation and consequently ocean transport, the physics underlying sea level rise, ice flux and mass budget, surface stress, unification of worldwide height systems, or in general a measure of surface mass balance?

Future Satellite Measurements of Time-Dependent Gravity: Applications for Hydrology, Oceanography, and Glaciology

John Wahr and Mery Molenaar, Department of Physics and Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado 80309 USA, and Frank Bryan, National Center for Atmospheric Research, Boulder, Colorado 80307 USA

Changes in the distribution of mass within the earth and on its surface can cause time-dependent fluctuations in the earth's gravitational field. These fluctuations are certain to be small over time periods of decades or less - many orders of magnitude smaller than the static field, for example. But many of them are large enough to be potentially observable in satellite gravity data. Existing satellite ranging data have been used in a number of studies to identify secular trends and seasonal variations in the very longest wavelength zonal gravity coefficients. These have been variously interpreted as due to the effects of post-glacial rebound and of present-day changes in polar ice mass (for the secular trends), and of the atmosphere (for the seasonal variations). Future dedicated satellite gravity missions could cause a dramatic improvement in the spatial resolution of the time-varying results. It might be possible to use the data from such missions to address problems in a wide variety of disciplines, from oceanography to hydrology to glaciology to solid earth geophysics. In this talk, we will discuss some of these possible applications. We will compare results from geophysical models of various kinds, against estimated uncertainties from proposed satellite missions.

G10 Modelling of atmospheric parameters in geodetic observations

Convener: Dodson, A.
Co-Convener: Elgered, G.

MODELING OF IONOSPHERIC PARAMETERS WITH HELP OF NAVIGATION SATELLITE SYSTEM

Andrianov V.A., Marchuk V.N., Shtern D.Ya., Mosin E.L., Smirnov V.M., Rusakov V.K. Institute of Radioengineering&Electronics of RAS, Russia

Method and appropriate software enabling on real dual frequency pseudorange measurements to satellite of navigation system "Navstar" is developed to receive high-altitude distribution (in range from 100 up to 1000 km) of electronic concentration of the Earth ionosphere. Results of processing satellite measurements data, in kind of high-altitude structures, received on September 27-28, 1996 in region of Moscow are submitted. High-altitude sounding up to height of a maximum of electronic concentration with use of the ground equipment of a multifrequency longwave radar RLK-M, intended for subsurface radiolocation of structure of planet ground and research their atmosphere, was simultaneously carried out. Comparison of high-altitude structures, obtained by an offered method and traditional, is conducted. A divergence is appreciated. The obtained results can be used for modeling high-altitude distribution of ionospheric parameters at solving problem of atmospheric correction in geodetic satellite observations.

GEODETIC NOISE AS METEOROLOGICAL SIGNAL : AN OVERVIEW OF GPS METEOROLOGY

Michael Bevis (Hawaii Institute for Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, USA)

For more than two decades space geodesists have been developing increasingly sophisticated means to calibrate the effects of propagation delays accumulated by radio signals as they pass through the earth's atmosphere. In recent years the approach favored by VLBI and GPS geodesists is to estimate key delay parameters directly from their geodetic observations. These so-called nuisance parameters can be estimated so well using continuous GPS (or CGPS) networks that they constitute valuable data sets for meteorology. This presentation will review the development of ground-based GPS meteorology, outline key areas of present-day research activity , and describe some of the long term demonstration and development networks recently established in the USA, Japan and Europe. While most of the key development activity is still largely geodetic in nature, I will discuss some issues of purely meteorological character (e.g. assimilation of GPS water vapor measurements into numerical weather models) because they are likely to impact the research agendas of geodesists working in this area. Lastly, returning to original theme of this session, some consideration will be given as to how the emergence of GPS meteorology might contribute to improvements in purely geodetic arenas.

DERIVATION OF PRECIPITABLE WATER FROM GPS DATA: AN APPLICATION TO METEOROLOGY

E. Borbas, Satellite Research Laboratory, Hungarian Met. Service P.O.Box 39. Budapest 1675 Hungary Tel/Fax:36-1 290-7387 E-mail: borbas@met.hu

A poster entitled:"Investigation of Integrated Precipitable Water Vapour using a Ground Based GPS Receiver" was presented at the last EGS meeting. In that paper it was demonstrated that it was possible to derive precipitable water from the zenith tropospheric delay measured from a ground based GPS receiver. The current paper presents new results, and in particular integrates observations from two types of GPS networks. The method is applied to the processed data to derive precipitable water for both cases. Comparison with meteorological data (radiosonde, NOAA TOVS) and numerical prediction model analyses are presented, and it is shown that the GPS method provides more accurate values of precipitable water vapour than conventional measurements.

ESTIMATING WATER-VAPOR GRADIENTS IN THE TROPOSPHERE USING GPS

J.L. Davis (Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts, USA)
G. Elgered (Onsala Space Observatory, Chalmers University of Technology, S-439 00 Onsala, Sweden)

In principle, the Global Positioning System (GPS) could be an extremely useful method for determining water-vapor gradients in the troposphere in the neighborhood (within 10 km) of the GPS site. Since signals are received from a number of different directions simultaneously, such gradients could be determined instantly. There has been little research in this area, because in practice multipath is a serious error source for the determination of time-dependent atmospheric gradients. There is hope, however, that multipath errors in GPS can be significantly reduced. In this presentation, we will assess quantitatively our ability to estimate gradients with GPS with current levels of multipath and with reduced multipath. We will also perform some experiments in estimating atmospheric gradients, and compare them to gradients estimated from water vapor radiometer (WVR) data.

ACCURACY OF ORBITS FOR GPS ATMOSPHERIC WATER VAPOUR ESTIMATION

A. H. Dodson and H. C. Baker (Institute of Engineering Surveying and Space Geodesy, The University of Nottingham)

A major error source in GPS measurements for precise height applications is the wet path delay due to tropospheric water vapour. It has recently been demonstrated that the tropospheric wet delay can be estimated using the strength of GPS data itself and converted to equivalent water vapour content with little additional uncertainty. One of the major factors in achieving accurate estimates is the availability of reliable, accurate orbits. The IGS precise ephemeris can be used for post-processed data sets (with approximately nine day delay), but for real-time applications, the main limitation at present relies heavily on the availability of rapid precise orbits on an equivalent time scale. Tests have therefore been performed investigating the accuracy of GPS water vapour estimates using a number of current freely available rapid and predicted orbits in comparison to the IGS precise ephemeris.

USING METEOROLOGICAL DATA ASSIMILATION MODELS IN ATMOSPHERIC DELAY MODELING

D.S. MacMillan (NVI, Inc./Goddard Space Flight Center, Greenbelt, MD 20771, USA)
C. Ma (Goddard Space Flight Center, Greenbelt, MD 20771, USA)

With the improvement of space geodetic techniques, the troposphere continues to be a significant source of random and systematic error. We have been investigating the possibility of calibrating atmospheric delay models with data from a meteorological data assimilation model.
We have examined the precision and accuracy of atmospheric mapping functions by comparing mapping function delays with raytracings of model atmospheric profiles. Variations in the atmospheric profile over a month typically result in hydrostatic mapping function delay variations of 40-50 mm at a 7 degree observation elevation. This translates to about 10-15 mm of variation in the estimated vertical. We present results of using model raytrace delays to derive the mapping functions for geodetic analysis of VLBI data.
Estimating atmospheric gradient parameters improves the precision and accuracy of VLBI estimates of baseline and station parameters and earth orientation parameters. Typically, the gradient delay at an elevation of 7 degrees varies by about 30 mm over the period of a year. We find that gradient parameters computed from the data assimilation model are correlated with the VLBI gradient estimates. We discuss the relative contributions of the wet and hydrostatic atmosphere to the total gradients measured by VLBI.

GPS WATER VAPOR FOR ASSIMILATION INTO NUMERICAL WEATHER MODELS

C. Rocken and T. VanHove (UCAR/UNAVCO, Boulder, CO 80301, USA)
D. Parsons, B. Kuo, X.-L. Zou and Y. Guo (NCAR, Boulder, CO 80301, USA)
D. Wolfe (NOAA/ERL, Boulder, CO 80303 USA)

Knowledge of the distribution of water vapor is crucial for many purposes in the atmospheric sciences from weather forecasting to climate studies. Analysis of the received signals from ground-based GPS receivers has been shown to provide accurate estimations of column integrated water vapor (IWV) contents. To date this analysis has typically been done several days after the measurements were taken due to a variety of factors. Such a delay is clearly not acceptable if this data is to be used as input to numerical weather forecasting. Recently we have begun routine processing of data from a 12-station NOAA-operated GPS network in real time. We use GPS data that is available hourly via phone lines, internet, and satellite communication links and predicted GPS orbits from the University of Bern. Our real time results are compared to post-processed GPS, radiosonde, and water vapor radiometer data. These comparisons demonstrate real time IWV accuracies of better than 2 mm. The value of the GPS water vapor data to weather forecasting is currently investigated by the National Center for Atmospheric Research (NCAR). NCAR scientists conducted a 3-week GPS experiment with 14 sites at 50-km spacing to determine the effect of GPS IWV on short term precipitation forecast. The experiment was conducted in association with the Atmospheric Radiation Measurement program. Preliminary results of the NCAR data assimilation experiment will be presented.

TROPOSPHERE MODELLING AND ESTIMATION TECHNIQUES FOR BASELINES WITH SMALL AND LARGE HEIGHT DIFFERENCES

M. Rothacher and S. Schaer (Astronomical Institute, University of Berne, CH-3012 Berne, Switzerland)
U. Wild (Federal Office of Topography, Section Levelling and Special Geodetic Tasks, CH-3084 Wabern, Switzerland)

The tropospheric refraction is — together with multipath and antenna phase center variations — one of the most important error sources in the determination of station heights with GPS. Using the data from permanent IGS sites in Europe different troposphere models and delay estimation strategies (including azimuthal variations) are studied and compared. Special attention is paid to the influence of the satellite elevation cut-off angle used in GPS data processing on the resulting station coordinates (heights in particular).
The baseline Zimmerwald–Jungfraujoch in Switzerland is closely examined in this context because this baseline, with a length of about 50 km and a height difference of more than 2000 meters, is particularly well-suited to test the effect of extreme height differences on the results obtained for station height and troposphere parameters. GPS solutions introducing a 4-dimensional troposphere delay model derived from surface meteorological data are compared to solutions solely based on GPS data.

A DETAIL ANALYSIS OF TROPOSPHERIC EFFECTS ON GEODETIC OBSERVATIONS AT TMGO

M. Schenewerk (NOAA/GL, Silver Spring, MD, USA), T.M. vanDam, G. Sasagawa (NOAA/GL, Boulder, CO, USA), N. Weston (NOAA/NGS, Silver Spring, MD, USA), S. Philipsen and K. Larson (Aerospace Dept., Univ. of Colorado, Boulder, CO, USA)

Improvements in geodetic tools are making previously subtle effects significant. Two examples affecting GPS observations are atmospheric loading of the Earth's curst and the troposphere, specifically the wet component. Each measurement, tropospheric delays and site coordinates, requires unambiguous determination of the other to achieve the highest accuracy.

Table Mountain Geophysical Observatory (TMGO) is a unique site where a long history of observations from two complimentary techniques, GPS and superconducting gravimetry, have been accrued. In particular, the superconducting gravity measurements provide a unique baseline for evaluating GPS vertical estimates over a variety of time frames. Positional estimates for TMGO using these techniques will be compared. Tropospheric effects will be identified and discussed. The ability for GPS to make subdaily, daily, and long term vertical estimates will be evaluated.

A NEW INSTRUMENTAL APPROACH FOR WATER VAPOR DETERMINATION BASED ON SOLAR SPECTROSCOPY

B. Sierk, B. Bürki, H.-G. Kahle, A. Geiger (Geodesy, ETHZ, CH-8093 Zurich, Switzerland)
St. Florek (ISAS, LMSU, D-12489 Berlin, Germany)

Microwave water vapor radiometers (WVR) are well established tools providing omnidirectional information on tropospheric water vapor and its changes both in time and space. These instruments make use of passive measurements of the emitted energy of water molecules in terms of brightness temperatures in two or more frequencies. In addition to this technique, a new instrumental approach for tropospheric water vapor detrmination has been developed. Its basic concept consists of high resolution absorption measurements towards the sun in the near infrared region by a solar spectrometer (SSM). The processing algorithm for the retrieval of integrated precipitable water vapor (IPWV) is based on a line-by-line calculation of the observed solar spectrum in a narrow wavelength interval of 1 nm width and a simple tropospheric absorption model. First measurements using absorption-, emission- and refraction-properties of water vapor have been accomplished in order to demonstrate the potential of this technique in a 30-day field experiment including SSM, WVR and GPS receivers. The comparison of these techniques showed an agreement within the individual accuracy limits and proved the potential of solar spectrometry. Important applications of this technique are seen in absolute determinations of wet path delays in permanent GPS networks as a low-cost calibration tool, in particular.

MODELING OF THE STATISTICAL ATMOSPHERIC PARAMETERS

A. A. Stotskii
Institute of Applied Astronomy, St.Petersburg, 197110, Russia.
E-mail: stotskii@isida.ipa.rssi.ru

The statistical properties of the path delay in the Earth neutral atmosphere are described by structure functions: temporal and spatial. Advanced models of these structure functions based on the statistical theory of turbulence and the data of observations are presented.
Random and regular components of structure function are considered. The contribution of dry and wet components of the path delay is discussed.
The structure functions are used for construction models of the others Earth atmosphere integral statistical characteristics such as the transfer function, the correlation interval of the signals passed through the atmosphere, and the average velocity of the path delay variations.

G11/OA21 Measuring and modelling atmosphere-ocean-land interactions

Convener: Gegout, P.
Co-Conveners: Dickman, S.R.; Laval, K.

INTERACTIONS BETWEEN ATMOSPHERIC PRESSURE FIELDS, THE OCEANS, AND EARTH'S ROTATION

S. R. Dickman (Geology Department, State University of New York, Binghamton, NY 13902-6000, USA)

The excitation of Earth's rotation by atmospheric pressure fluctuations, on time scales from days to years, is modified by the oceanic response to the pressure load. That response, including changes in mean sea level and associated currents, cannot be accurately described unless the frequency dependence and spatial structure of the loading are accounted for.
I have calculated frequency-dependent Green's functions which character-ize the rotational effects of the oceanic response to pressure loads associated with individual spherical harmonics. Computations were based on solutions to my dynamic spherical harmonic ocean tide model, with rotational effects determined using a "broad-band" approach. A convolution-type combination of the Green's functions with actual atmospheric pressure data then yields the effects of the "dynamic barometer" oceanic response on rotation. Results for the past decade have been obtained using harmonically decomposed NMC and EC pressure fields. Estimates of the combined atmospheric and (dynamic barometer) oceanic angular momentum time series for 1980 - 1990 will be presented and evaluated.

GEODETIC SITES DISPLACEMENTS INDUCED BY OCEANIC AND ATMOSPHERIC LOADINGS

P. Gegout and H. Legros (Ecole et Observatoire de Physique du Globe de Strasbourg, 5 rue Descartes, 67084 Strasbourg cedex, France)
R. Biancale (Centre National d'Etudes Spatiales, Groupe de Recherche de Geodesie Spatiale, 18 avenue Edouard Belin, 31055 Toulouse cedex, France)

Global atmospheric loading induces various interactions between atmosphere and oceans, between atmosphere and solid earth and between solid earth and oceans. We consider the static response of non-global oceans overlying an elastic Earth which is induced by the atmospheric loading located over the continents. This model take into account the significant oceanic response associated with the continental atmospheric loading, relative to ocean - solid earth interaction. Temporal variations of geodetic (SLR, VLBI, ...) sites positions driven by global atmospheric loading and non-global oceanic loading are derived using a global atmospheric pressure data set provided by the European Center for Medium range Weather Forecasts.

THE REPONSE OF NON-GLOBAL DYNAMIC OCEANS TO GLOBAL ATMOSPHERIC FORCING

P. Gegout and H. Legros (Ecole et Observatoire de Physique du Globe de Strasbourg, 5 rue Descartes, 67084 Strasbourg cedex, France)

To investigate the geodynamical consequences of Atmosphere-Oceans-solid Earth interactions, we present a basic dynamical model of the oceans which include the oceanic response to global atmospheric forcing. The processes of interaction between solid earth and non-global oceans induced by continental atmospheric loading are modelled. Hydrodynamic equations are solved using spectral methods and generalized spherical harmonics. Spectral solutions of the hydrodynamic equations yield for each spatial scale (i.e. for each spherical harmonic's degree and order) the frequency-dependent response of the oceans. For periods greater than ten days, the oceanic response aims to the static equilibrium of a non-global ocean overlying an elastic Earth. We discuss the influence of Earth's deformations on large scales oceanic masses redistributions. We also underline the fact that the daily variability of atmospheric and oceanic masses distributions have major consequences on Earth's rotation.

ATMOSPHERIC LOADING OBSERVED BY VLBI

R. Haas (Geod. Inst. Uni Bonn (GIUB), Nußallee 17, D-53115 Bonn, Germany)
H. Schuh (DGFI, Abt. I, Marstallplatz 8, D-80539 München, Germany)

Air pressure lows and highs (cyclones and anticyclones) can be regarded as time-dependent loading on the Earth's surface. According to their geometry they generate large-scale deformation fields with some hundred up to some thousand kilometres wavelength. The periods of the loading function are between a few days and some weeks. There is also a diurnal pressure variation corresponding to the solar S_1 tide and an annual period of the global air pressure distribution. Such air pressure anomalies can cause vertical displacements in the centimeter range and horizontal displacements in the millimeter range. The influence of atmospheric loading corrections on the results and the accuracy of VLBI experiments (Very Long Baseline Interferometry) has been investigated. For the site dependent pressure responses a model of Manabe et al. (1991) was used which gives loading coefficients for the most important geodetic VLBI s tations. The amplitudes of local and mean annual air pressure variations can easily be obtained from VLBI station logs and weather charts for the duration of the VLBI experiments. Loading coefficients have also been determined by a VLBI global solution. The correlation coefficients between these coefficients determined empirically and those given by the theoretical model are higher than 0.6. Thus, the VLBI results in general confirm the theoretical model but show signifi cant anomalies for some stations, e.g. for Onsala (Sweden). The validity of the inverted barometer hypothesis was tested by VLBI, too.

APPLICATION OF THE HD MODEL IN THE ACSYS REGION:

Stefan Hagemann and Lydia Dümenil (Max Planck Institute for Meteorology, Bundesstr.55, 20146 Hamburg, Germany)

The representation of hydrological land surface processes is still not being treated adequately in atmospheric global circulation models (GCMs). In particular the lateral waterflows from the continents into the ocean have so far been described in an insufficient way. A model was developed which describes the translation and retention of the lateral discharge on the global scale as a function of the spatially distributed land surface characteristics which are globally available. Here, global scale refers to the resolution of 0.5° and lower, corresponding to a typical average GCM gridbox area of about 2500 km^2.

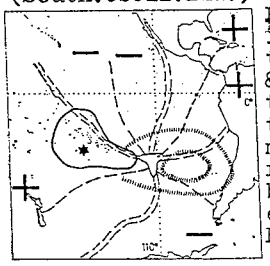
The **Hydrological Discharge model** or **HD model** separates between several flow processes such as overland flow, baseflow and riverflow. As both the retention and translation of a flow process need to be simulated, a two-parameter model is required. In the HD model this is applied to overland flow and riverflow. For baseflow a one-parameter model is sufficient. A first parameterization approach using gridbox characteristics was developed.

The HD model is applied to the ACSYS region using input from several atmospheric GCMs (ECHAM4-T42, ECMWF-Reanalyses, NCEP Reanalyses). The simulated inflows into the Arctic Ocean and its subcatchments are compared to observed inflows which were provided by GRDC. Based on this comparison the quality of the input from the different atmospheric GCMs is judged.

LITHOSPHERE-ATMOSPHERE INTERACTION AND EL-NIÑO

G.G.Kochemasov,IGEM,Russian Academy of Sciences

Wave sectoral structure of cont.hemisphere of 4 alternating risen/+/& fallen/-/sectors(having 8 subsectors)is centred at the Pamirs and has its antipod in ocean.hemisphere:centre in Easter Is. rise/Kochemasov,1995/.Highly risen &"anomalous" Tibet is antisymmetric to South Pacific "Superswell"(*)also anomalous in bathymetry & petrology.Both sectoral structures have mirror reflection in the CMB.High pressure atmospheric cell (inner cont.1020mbar)producing much of the SOI (South.Oscil.Ind.)change signalling beginning of El-Niño,is centred over Chilean subsector.Anomalous spots in lithosphere(Superswell) & atmosphere are opposite in the sector structure.There is tendency to equalize angular momenta of 2 anomalous deeply rooted subsectors separated by Easter Is.& EPR.Ang.momen. exchange is a tool creating ENSO.



EFFECT OF THE TIBETAN PLATEAU UPLIFT ON MONSOON SIMULATED BY THE LMD AGCM

K. Laval and J. Polcher (Laboratoire de Meteorologie Dynamique, Ecole Normale Superieure, Paris, F-75231 France)
X. Le Pichon and P. Henry (Laboratoire de Geologie, Ecole Normale Superieure, Paris, F-75231 France)

It has been recently proposed that a large change in the monsoon regime occured about 8 My ago at the end of Miocene and that this change was triggered by a geologically rapid uplift of the Tibetan plateau. The climate simulations performed with the LMD Atmospheric Circulation Model (AGCM) have shown that this model was able to reproduce rather realistically the monsoon variability on seasonal and interannual scales. We have thus used this model to simulate the climate changes associated with variations of the height of the Tibetan plateau through geologic times. The results of the simulations show that the monsoonal atmospheric circulation varies with increasing height of the Tibetan plateau. However, this variation shows regional contrasts over South-East Asia and India that we will discuss. The southwestern winds over Arabian sea are stronger with surface uplift over the Tibetan plateau, but, simultaneously, they are weaker over southern India and the Bay of Bengal. The precipitation changes vary also regionally showing a displacement of the maximum convergence zone in latitude. The results of these simulations are compared with the geologic indicators of climate change in the Indian ocean and within the Himalaya foothills at the end of Miocene about 8 My ago.

Tidal Deformations of the Continental and Oceanic Lithospheric Blocks and Their Differential Westward Movement

L.A.Maslov, Computer Center RAS, 65 Kim Yu Chen Str., Khabarovsk, Russia.
E-mail: leom@farcast.khv.ru

Tidal deformation in the solid earth is a sort of a "high frequency" vibration, acting in a fractured, inhomogeneous substance over a long period of geologic time. These deformations are distributed in the earth unevenly: higher magnitudes of the vertical (radial) deformations are observed in the continental area, and lower radial deformations (due to the dampening effect of the water layer) are observed in the oceanic part of the earth. Besides, it is reasonable to suggest that the tidal deformations are not equally distrubuted along the earth's radius, but rather concenrtrated in one of the layers (probably asthenosphere). To describe adequately these deformations we used a model of a loose medium. The plane problem of "tidal" deformation in a circled area, containing the inner nondeformed core was considered. Two differential equations of the second order, describing lateral motion of a particles, caused by vertical tidal deformations are arrived at. It is shown that the rate of the westward drift of the lithosphere depends on the amplitude of the vertical deformations of the latter. Precisely, this rate is proportional to the amplitude of the vertical deformations squared. The amplitudes of the solid earth tidal deformations in the oceanic areas are lower in comparison with those in the continental areas due to the dampening effect of the water layer. As a consequence, there occurs a more rapid westward drifting of the continental lithosphere than that of the oceanic one.

EARTH ROTATION AND POSTGLACIAL RELATIVE SEA LEVEL HISTORY

W.R. Peltier (Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7)

Although it has become commonplace to investigate the impact of the late Pleistocene glaciation-deglaciation cycle upon Earth rotation, there has been less attention payed to the issue of the feedback of such variations in rotational state upon postglacial sea level. Several recent analyses have suggested that this feedback warrants consideration. In Peltier (1994; Science, 265, 195-201) a series of detailed comparisons of coral based and U/Th dated records of postglacial rsl history were discussed, principally those from the Island of Barbados in the Caribbean Sea and from the Huon Penninsula of Papua New Guinea, which suggested that these records were well fit by a global viscoelastic theory of postglacial sea level change but only if the usual corrections for tectonic uplift at these sites were not applied. The theory then predicted the observed 13 m offset between these records that obtains just subsequent to the Younger-Dryas epoch. The implications of this result have recently been debated by L. Edwards and W.R. Peltier (1995; Science, 267, 536-538). Here I will describe a series of investigations performed to determine whether or not the feedback of deglaciation induced variations of Earth rotation upon sea level history is capable of modifying the predicted histories at these sites so as to allow the usual corrections for tectonic uplift to be applied. The analyses are based upon the ICE-4G deglaciation history of Peltier (1994) and mantle viscosity profiles inferred on the basis of formal inverse theory by Peltier (1996; Science, 273, 1359-1364).

THE ANNUAL POLAR MOTION EXCITATION.

R. Abarca del Rio (UMR5566, 14 Av Edouard Belin, 31400 Toulouse, France)

In this paper we study the atmospheric, oceanic and terrestrial hydrological cycle excitation of the annual polar motion. We will particularly devote our presentation to the oceanic excitation as obtained from the analysis of Topex/Poseidon sea level data. We will discuss the steric correction applied (using the Levitus climatology and sea surface temperature) and the different hypothesis for obtaining the oceanic currents from surface measurements. We will also show our results concerning the atmospheric excitation : geographical variation in pressure and their effect in polar motion, and the analysis of different sets of winds. The hydrological components are derived from a run of the UGAMP model with climatological fluxes. Both the soil moisture and snow depth shows little effect when compared with oceanic or surface pressure excitation. After adding the all terms (hydrological, oceanic and atmospheric) the results coincide with the annual polar motion excitation. But the until today negligible reservoirs (hydrological and winds) could be more important than thought, and play a great role on the annual polar motion excitation. This paper also shows the validity of the inverted barometer correction at the annual period.

TWO LAND SURFACE SCHEMES IMPLEMENTED IN THE SAME GCM

J.-P. Schulz, L. Dümenil (Max-Planck-Institut für Meteorologie, Bundesstr. 55, D-20146 Hamburg, Germany) and
J. Polcher (Laboratoire de Météorologie Dynamique du CNRS, 24 rue Lhomond, 75231 Paris, France)

Land surface processes have a significant impact on near surface climate phenomena. They determine, among others, near-surface sensible and latent heat fluxes and the radiation budget, and thus strongly influence atmosphere and land characteristics such as temperature, humidity or cloud formation. The two land surface schemes ECHAM and SECHIBA which were implemented in the same atmospheric general circulation model (GCM) ECHAM4 are compared. This allows to investigate the role of atmospheric feedback effects which may yield a different evolution of the surface and subsequently the dynamics fields. Global experiments which were performed with the two schemes using the same initialization and climatological sea surface temperatures indicate that the land surface parameterizations have a significantly different impact on the atmosphere. Such differences in the results may be related to certain model characteristics. Global scale results for the atmospheric response to the different land surface schemes are presented. We will analyse the impact on the atmospheric circulation and water cycle and the land surface energy and moisture fluxes.

Non-stationary model of oceanic and atmospheric boundary layers interaction

V.Shnaidman, A.Tarnopolsky
Odessa Hydrometeorological institute

The turbulent processes in atmospheric and oceanic boundary layers considered as one system and simulated with the hydrodynamics equations and turbulence closure on the turbulence kinetic energy and dissipation equations. Wave layer processes are taken into account on the description of the wind wave collapsing, which was related with the atmospheric friction velocity. Profiles of meteorological and hydrophysical values, turbulence characteristics and interaction parameters, including the surface currents and temperature of the ocean and turbulent fluxes are determined in common. These functions are calculated to the given conditions on the external boundaries of the interactive layers.

FRICTION AND MOUNTAIN TORQUE MECHANISMS OF EARTH-ATMOSPHERE MOMENTUM EXCHANGE

D.A. Salstein (Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge, MA 02139 USA)
H. Iskenderian

The atmosphere exchanges momentum across its lower boundary by means of both tangential forces of winds against underlying ocean or land and normal pressure gradient forces against mountainous topography. When viewed in the context of the rotating planet, these two actions lead to so-called friction torques and mountain torques that act to change the angular momentum of the atmosphere and the rotation rate of the planet below. Over the ocean, friction torque, which tends to dominate on monthly and longer scales, has been estimated by modeling approaches that are based on surface wind values and the characteristics of the boundary layer. Measurements from scatterometry have yielded new information on the near-surface wind vector, and use of torques based on this approach often improve calculations of the angular momentum balance. On the other hand, mountain torques are particularly strong at the highest frequencies, when they are related to the movement of synoptic-scale weather systems across mountainous features, notably in the winter hemisphere. On such periods of about ten days and under, the Rockies, Andes, and Himalayas have a particularly strong impact on angular momentum exchange between atmosphere and solid Earth.

MULTIPLE EQUILIBRIA AND EIGENMODES OF A SINGLE-GYRE BAROTROPIC WIND-DRIVEN OCEAN CIRCULATION

V.A. Sheremet (Woods Hole Oceanographic Institution, MS#21, Woods Hole, MA 02543, USA)
G.R. Ierley (Scripps Institution of Oceanography, La Jolla, CA 92093-0225, USA)

A barotropic model of the wind-driven circulation in the subtropical region of the ocean is studied using Chebyshev spectral method. Formation of the recirculation gyre following the separation of the western boundary current from the coast is emphasized. For a geophysically relevant values of viscosity and nonlinearity multiple steady solutions of a boundary-layer, recirculation gyre and basin-filling-gyre types are found. A linear stability analysis reveals several classes of modes: basin modes of Rossby waves, modes associated with the recirculation gyre (resulting in the multiplicity of steady solutions), western boundary wall-trapped modes and a "resonant" mode. Their role in determining the mean ocean circulation and connection to the temporal variability is analyzed.

QG, BAROTROPIC, WIND-DRIVEN GYRE MODEL: MODERATE REYNOLDS NUMBER VISCOSITY DEPENDENCE

D. N. Straub and R. B. Scott (McGill University, Montreal, Canada, H3A 2K6)

In the classical view of wind-driven, mid-latitude ocean gyres, energy is input to the geostrophic flow by the winds and is dissipated primarily in western boundary currents and their seaward extensions. This dissipation is linked to poorly known and highly parameterized closure schemes (e.g., eddy viscosities) which are meant to account for the net effect of subgrid scale processes. Both the inverse energy cascade of geostrophic turbulence and the lack of known mechanisms that transfer energy between (quasigeostrophically) balanced and unbalanced flow bring into doubt this view of the energetics. This raises the question of whether the wind power input to the QG flow may shut off as the eddy viscosity becomes small. This question is addressed in the context of steady solutions to the barotropic QG equations, forced by an idealised double gyre wind- stress pattern. This system has multiple equilibria, and the results were found to be sensitive to the dynamic boundary condition imposed and to the symmetry of the solution. In all cases, the the geostrophic velocity and wind fields do decorrelate as the Munk number is decreased. One solution type was found to decorrelate fast enough for the power input to the gyres to decrease with Munk number, even with the lowest Munk numbers investigated. This resulted in solutions that, for some regions of parameter space, had kinetic energy only weakly dependent on the value of the eddy viscosity.

Award applied for: Keith Runcorn travel award

SEASONAL VARIATIONS OF BASELENGTHS FROM VLBI DATA ANALYSIS

O.A. Titov (Institute of Applied Astronomy, Zhdanovskaya str., 8, 197110, Sanct-Petersburg, Russia)

Annual and semiannual variations in baselengths were detected from special investigation of large amount of VLBI data results. Amplitude of both types of them increases with baselength. It means that variations of VLBI station vertical components has the most income into the phenomena. There are a few possible explanations of the effect. For example, strong correlation with AAM functions is observed. It can be interpretated as a influence of global atmospheric pressure oscillations on the Earth crust. Taking into account of the effect will help to increase an accurasy of VLBI data global adjustment in future.

G12 Developments in spectral stochastic techniques for gravity field modelling

Convener: Tziavos, I.N.
Co-Convener: Vermeer, M.

ESTIMATION OF THE REGULARIZATION PARAMETER BY MEANS OF THE COVARIANCE MATRIXES SPECTRAL EXPANSIONS

O.A. Abrikosov, A.N. Marchenko (State University "Lviv Polytechnic", S.Bandera St. 12, 290646 Lviv-13, Ukraine)

Using the Tikhonov's regularization as the generalization of the least squares collocation method we considered the estimating of the regularization parameter on the basis of the following traditional approaches.

- By the principle of generalized misclosure.
- By the applying of the corresponding solution norm.
- By the combination of two above mentioned approaches.

These approaches were realized by means of the Euclidean norms of corresponding covariance matrixes. The spectral expansions of these matrixes provide the simply computing estimates for quasioptimal values of the regularization parameter accordingly to each considered approach. Finally, these estimates were expressed (in the closed forms) in the terms of the gravity field variance and the measured data accuracy only. The most interesting cases of regularization parameter (α=0 and α=1) have been treated separately in view of the obtained closed expressions.

THE USE OF LEAST SQUARES COLLOCATION METHOD IN GLOBAL GRAVITY FIELD MODELING

D. Arabelos (Department of Geodesy and surveying, Aristotle University of Thessaloniki, GR-540 06 Thessaloniki)
C.C. Tscherning (University of Copenhagen, Department of Geophysics, Juliane Maries Vej 30, DK-2100 Copenhagen Oe)

Least Squares Collocation (LSC) is a very flexible method in gravity field modelling, which permits the use of data of different kinds and with different noise-characteristics. It also permits the computation of drift parameters and of error estimates of both computed values and parameters. The method has however the drawback that one needs to solve a system of normal equations involving as many unknowns as the number of data and parameters. The global use of the method have therefore been restricted to the use of block mean values as input data. The combined use of point and mean values could be possible if finite instead of full covariance functions could be used. Preliminary prediction results using LSC with finite covariance functions showed satisfactory agreement with corresponding results obtained with full covariance functions in the cases where the finite covariances fit satisfactory the corresponding full covariances. Some new experiments showed that it is possible to find some general procedure to approximate full by finite covariance functions without significant loss in the quality of the prediction. The computational savings which might be gained in finite covariance functions shows that LSC in the future could be used globally. Iterative solutions based on solutions where finite covariance functions are used may be the way to go.

HIGH-DEGREE SPHERICAL HARMONIC ANALYSIS COMBINING GRIDDED AND RANDOM DISTRIBUTED DATA SETS

T. Auzinger and W.-D. Schuh (Institute of Theoretical Geodesy, Graz, Austria)

A rigorous least squares adjustment of high degree spherical harmonics yields a very large normal equation system. This presentation reports on the numerical problems to solve this system and to obtain accuracy estimates by error propagation. Two different scenarios, gridded data only and combined systems without gridded low order (dense) and gridded high order (sparse) measurements are investigated. In both cases an optimal reordering strategy makes it possible to decompose the normal equation system in a very efficient way (no fill-in elements). A special adapted Cholesky-factorization and partial inversion algorithm form a well tailored strategy to benefit from this special sparse structure.

A COMPARISON BETWEEN THE ITALGEO95 AND GPS/LEVELING DATA ALONG THE COAST OF ITALY

Barbarella M.*,Barzaghi R.**,Dominici D.*,Fiani M.***,Gandolfi S.* and Sona G.**
* DISTART- University of Bologna(Italy)
**DIIAR-Sezione di Rilevamento. University of Milan(Italy)
***Istituto Universitario Navale.Naples (Italy)

The new Italian garvimetric quasi-geoid Italgeo95 has been tested with a large data set of GPS/leveling data. A GPS network has been carried out along the coast of Italy,these GPS verteces include around 100 benchmarks of the Italian leveling network. This whole network has been adjusted and so has been obtained the ellissoidic heights of all the benchmarks. Another GPS network has been carried out near the Ravenna coast. In this area a large high precision leveling network was set up by local authorities and connected to some benchmarks located in the stable zone of the Appennines. GPS static survey were executed contemporaneously to a repetition of the spirit leveling survey and these points were used as reference for a successive fast-static survey. On such data sets, a reliable and valuable comparison can be carried out in order to analyze the different spectral properties of the residuals. After a GPS and leveling data validation,differences has been computed between N coming from GPS/leveling and N (Italgeo95).The residuals display both high and low frequency behaviours. The low frequency component of the residuals is clearly connected to the reference geopotential model OSU91A which has the same pattern in the residuals. On the other hand, the high frequency component contains a lot of information which have been deeply investigated, especially in areas of sharp geoid variatons,to point out possible high frequency distorsions in the gravimetric quasi geoid. This has been done not only to assess the quality of the actual geoid estimate but also for integrating the GPS/leveling data set with gravity to compute in the future the Italian geoid with an etherogeneous data set.

THE FIRST NORTHERN MOROCCAN GRAVIMETRIC GEOID

E.H. BENAIM (Institut Agronomique et Vétérinaire Hassan II, Dépt. de Géodésie et Topographie, BP.6202 Rabat-Instituts, Rabat, Morocco).
M.TAKHCHI (Division de la Carte, Ave My Hassan Ier, Rabat, Morocco).
L. TIKDJRINE (Division de la Carte, Ave My Hassan Ier, Rabat, Morocco)
M.J SEVILLA (Instituto de Astronomia y Geodesia, 28040 Madrid, Spain).

The first Northern Moroccan gravimetric geoid has been established based on the following data: a) - The global geopotentiel model OSU91A spherical harmonic set; b) - 30950 BGI point free air garvity anomalies; c) - 933 D.M.A point free air gravity anomalies; d) - 2400 point free air gravity anomalies deduced from new observations which have been made in 1988 and 1989 by the moroccan geodetic Division; e)- a 1000x1000m DTM to calculate the terrain correction and indirect effect. The oral communication is organized in three parts. The first part will focus on the gravimetric data acquisition and the processing of the new gravimetric observations. One will conclude this first part with an outlook on the terrain correction and the indirect effect applied to data and on gridding method used in this job. The second part will discuss two Stokes integration methods applied in the computation: local and numerical integration and Fast Fourier Transform methods. These two methods have been combined to a remove and restore technique and they have used the same gridded gravimetric residuel anomalies with respect to the global geopotentiel model OSU91A. In the last part, the results are presented with a comparison to the GPS/levelling determinations which showed a good agrement.

THE NEW SYSTEM OF FOURIER ANALYSIS FOR THE EARTH' GRAVITY FIELD

S.F. Bian (Geodätisches Institut, Universität Stuttgart, Keplerstraße 11, 701174 Stuttgart, Deutschland)

By means of B-splines and sinc-functions as well as Fourier analysis itself, the new system of Fourier transform is in detail formulated in this contribution. Use of the continuous Fourier transform is emphasized in the new system whereas the extensively implemented DFT is discrete and only a particular case of the new system. The singularity of frequency response functions in the new system is completely eliminated by introducing a new variable. Compared to the existing DFT in the physical geodesy, the new system may yield a more convergently and accurately numerical results. Some preliminary simulation examples are discussed in the contribution to illustrate a superiority of the new system.

REGULARIZATION IN GRADIOMETRIC ANALYSIS

J. Bouman and R. Koop (DUT, Faculty of Geodetic Engineering, Delft, The Netherlands)

The determination of the earth's gravity field from satellite observations, for example gradiometry, requires regularization in order to obtain stable solutions. Usually this regularization consists of a priori information like Kaula's rule. The direct use of Kaula's rule may be interpreted as a constraint on the smoothness of the signal, i.e. gravitational potential.
Since we are dealing here with satellite gradiometry it is natural to look at the smoothness of the second derivative of our signal. The consequences for the regularization parameter are considered, as well as the consequences for the quality of the solution in terms of bias and precision. Several mission scenario's will be examined in this way.

FIRST NUMERICAL RESULTS IN DETECTING HETEROGENEITIES IN REGIONAL GRAVITY FIELD USING GPS UNDULATIONS

M. Doufexopoulou, V. Pagounis (Department of Geodesy, NTU, Athens, 9 Heroon Polytechniou Str., Gr. 157 73 Zographos, Athens, Greece)

In the global or regional scale, the geoid undulations can be considered as high pass filtered free air gravity anomalies. For these scales, the heterogeneity of the gravity field can be investigated with "objective" information, in which no bias from the regional gravity data are introduced. In this approach the geoid undulations computed by a geopotential model truncated at various degrees of expansion, are subtracted from accurate GPS undulations of a regional survey. Then, the numerical behaviour of how the residual undulations vary per degree of expansion and how this variability, for neighboring points depends on their geographical location is examined. Simple statistical tests are used, that operate towards the detection of heterogeneities of the gravity field that relate to the Newtonian effect of deeper masses. An initial configuration of the method is presented and some first raw numerical results for the SE part of the Mediterranean are given. Results are in accordance to the regional tectonic pattern.

THE USE OF SPECTRAL TECHNIQUES IN GRAVITY FIELD MODELLING: TRENDS AND PERSPECTIVES

R. Forsberg (KMS, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark, rf@kms.min.dk)

The use of stochastic and deterministic Fourier-based methods are now widespread in physical geodesy, and have been used extensively for geoid determination, recovery of gravity anomalies from satellite altimetry, and for the general solution of the geodetic boundary value problems. Suitable methods now exist both in planar and spherical approximations for most problems. This paper reviews the developments of the last decade or so, and highlights the present trends in the applications and some outstanding problems.

A MAXIMUM MASS CONCENTRATION, POINT MASSES AND THE EXTERNAL GRAVITY FIELD

P. Holota (Research Institute of Geodesy, Topography and Cartography, 250 66 Zdiby 98, Praha-východ, Czech Republic)

Let B be a set of all positive mass distributions inside Ω (the body of the Earth) such that on a given set of surface points (profile) their potentials reproduce the gravity potential of the Earth and have a common center of gravity. The principal objective of this paper is motivated by the following question: Does there exists a mass distribution $\mu_0 \in B$ such that it is concentrated as much as possible around the Earth' center of gravity, i.e., that it has a "smallest" support? (Note that $\text{supp}\,\mu_0 \equiv \overline{\{x \in \Omega; \mu_0(x) \neq 0\}}$, where the bar denotes the closer in 3 - dimensional Euclidean space.) A question like this was not solved completely so far. Nevertheless we believe that there is a real content in an attempt to find, though in an approximation way, the distribution μ_0. In our approach, considering the méthod de balayage and the objective above, we will also give a set of point masses related to a standard gravity field model.

DETAILED GRAVIMETRIC GEOID FOR THE EGYPTIAN SOUTH-WESTERN DESERT

Hussein A. Abd-Elmotaal (Civil Engineering Department. Faculty of Engineering, Minia University, Minia 61111, Egypt; e-mail: hamotaal@frcu.eun.eg)

Different gravimetric geoid solutions were carried out for the south-western Egyptian desert. A set of 2682 measured gravity stations were available for this investigation. The discrete gravity data are reduced to the geoid through the free-air reduction. Also terrain reduction is performed using a trivial $30'' \times 30''$ Digital Height Model for the test area. Different earth's geopotential models were used for the removing of the reference field. The geoid computations were performed in the space domain using both the least-squares collocation technique and the discrete Stokes integration technique. For the latter technique, the reduced gravity anomalies are gridded on a $5' \times 5'$ geographical grid using the least-squares interpolation technique with local covariance functions. A wide comparison among the different geoid solutions is made. The strange behaviour of the gravity field of the test area is treated and discussed in detail.

Optimal spectral combination method used in French geoid determination

Z. Jiang
Institut Géographique National, F-94160, Saint Mandé, France

Nowadays, the geoid determination is based on the combination of heterogeneous data sets. In this paper, special attention is focused on the combination of a geopotential model and the terrestrial gravity data. Considerable great wavelength's errors have been found in the gravimetric geoid solution using the simple combination method. This result can be greatly improved by using an optimal spectral combination method.

Comparisons are made: 1) between different solutions obtained by changing the combination and the spectral weighting techniques; 2) between the gravimetric solutions and a GPS levelling points implied geoid solution.

Concerned problems, such as numerical techniques and optimal combination between the gravimetric geoid and the GPS levelling data are also discussed.

THE ANALYSIS OF GEOID SOLUTIONS, THEIR FITTING TO GPS/LEVELLING POINTS IN LATVIA

J. Kaminskis (State Land Service, 11. Novembra krastmala 31, LV-1050 Riga, Latvia)
R. Forsberg (National Survey and Cadastre, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark)

Abstract: We have used different methods and gravity data for Latvia geoid determination. Besides our terrestrial gravity data (12 200 points) we have used draped altimetry data from ERS-1 geodetic mission and new ship data from the Baltic sea in September and October 1996 for geoid determination. The last data are important for draping satellite altimetry derived gravity into terrestrial gravity. Final geoid computations were carried out by spherical Fast Fourier Transform (FFT) techniques on a regular grid of 1.5'X 3.0'.

The newest global spherical harmonic gravity reference model EGM96 to degree and order 360 fits better for our territory than previous reference models. Practically we are interested in high geoid accuracy up to one centimeter in the area 55.5<latitude<58.5 and 20.0<longitude< 28.5 degree. In mentioned area we have tried to fit our gravimetric geoid solution to 32 national base net GPS/levelling points. After 4-parameter empirical datum fit of geoid to GPS/levelling points received standard deviation is 8 cm. We have tried to deform fitted geoid or "surface" with the aim to obtain artificial supper accurate geoid for test in practical use by GPS, too. By such action we have to includ in gravimetric geoid uncertain errors from GPS/levelling height determination (so far it is not distinguished).

Practically approved Latvian geoid solutions going to be presented together with examples from our experience and analysis of achieved results.

COLLOCATION IN REPRODUCING KERNEL HILBERTSPACES OF A MULTISCALE ANALYSIS

W. Keller (Geodetic Institute, Stuttgart University, Keplerstr. 11, 70174 Stuttgart, Germany)

Collocation in reproducing kernel Hilbertspaces is a very flexible tool for the combination of observation of different types. The main disadvantage of this approach is the necessity to invert a matrix, having the size of the number of observations. In general this matrix is fully occupied, due to the fact that the base functions of the Hilbertspace do not have compact supports.

On the other hand it is well known that the scaling spaces of a multiscale analysis ,connected to a wavelet analysis of the signal, constitute reproducing kernel Hilbertspaces. Because these spaces are spanned by the shifted versions of the scaling function, having a compact support, the reproducing kernel is rapidly decreasing and leads to diagonal or band-shaped collocation matrix. Hence, by using scaling spaces of a wavelet analysis as reproducing kernel Hilbertspaces a major disadvantage of collocation can be overcome.

The paper is to develop the theory of collocation in scaling spaces of a multiscale analysis and to test the performance of the resulting algorithm.

PROGRESS IN SPECTRAL METHOD FOR ANALYSIS AND INTERPRETATION OF THE MODEL GRAVITY FIELD

A.L. Kharitonov (Inst.of Terrestrial Magnetism, Ionosphere & Radiowave Propagation, Moscow reg, 142092, Troitsk, Russia)
S.A. Serkerov (State Academy of Oil and Gas, Moscow, Leninskiy st., 65, 117917, Russia)
G.S. Hassan (National Research Institute of Astronomy and Geophysics, Helwan, Egypt)

In this paper an analysis of the main errors of spectral method of the gravity field investigation is performed. To estimate a degree of spectrum reliability depending on the length of profile, the empiric approach was used with an application of numerical methods. The spectrum was calculated using the discrete Fourier transformation by Simpson method. The results of computations show that if the gravity field is generated by an isolated model body. This approach to the problem allows not only carry out the spectral analysis of different elements of gravity field, but to separate the effects of singular points, distributed at different levels along a vertical. This approach to the problem is very helpful because of the gravity field complexity - the field data are included in the gravity field parallel with a number of highand low-frequency noises, what is makes difficult for the gravity field interpretation.

PRECISE GEOID DETERMINATION USING A DENSITY VARIATION MODEL

N. Kuehtreiber (Institute of Theoretical Geodesy, Technical University Graz, Steyrergasse 30, A-8010 Graz, Austria)

The recomputation of the Austrian Geoid within the project GEOID2000 is planned to reach centimeter level accuracy. For the last Austrian geoid computation a digital surface density model with 1.5' x 2.5' grid distance was established. While the information about the density did not become better the digital height model improved both in resolution and accuracy. The contribution of the digital density model and the high resolution height information to the determination of a precise geoid is investigated.

PHYSICAL INTERPRETATION OF THE TSCHERNING-RAPP KERNEL

A.N. Marchenko, O.A. Abrikosov (State University "Lviv Polytechnic", Faculty of Geodesy, S. Bandera St. 12, 290646 Lviv-13, Ukraine)

In the proposal paper we continue our studying of the anomalous potential T parametrization in view of the operational approach to physical geodesy. Three following problems were solved.

- The interpretation of the Tscherning-Rapp global covariance function as the finite set of the special potentials.
- The interpretation of the Tscherning-Rapp kernel and it's constituents by the simple (two-parameter) laws of the Earth's density distribution according to investigation of Legendre, Laplace, Radau, Darvin, Roche, etc.
- The extracting of the Tscherning-Rapp kernel main terms in view of physical interpretation and the behavior of their spectral characteristics.

As a result, this studying leads to the construction of the new kernels set. Such set is based on the Tscherning-Rapp kernel constituents and connects directly with the theory of the linear and source harmonic functions.

RECENT EVALUATION OF THE EUROPEAN GRAVIMETRIC QUASI-GEOID EGG96 FOR EASTERN EUROPE

P.P. Medvedev (Russian Academy of Sciences, Geophysical Center, 3, Molodezhnaya Str., Moscow, 117296, Russia)

G.V. Demianov (Central Research Institute of Geodesy, Air Survey and Mapping of the Federal Service of Geodesy and Mapping of Russia (ZNIIGAiK), Onezhskaya 26, Moscow, Russia)

H. Denker, W. Torge (both at Institut für Erdmessung, Universität Hannover, Schneiderberg 50, D-30167 Hannover, Germany)

In 1996 a new European gravimetric quasigeoid EGG96 was computed at the Institut für Erdmessung (IfE). This model is based on high resolution gravity and terrain data in combination with the global geopotential model JGM3/OSU91A (max. degree 360). The computation of the model EGG96 is based on the spectral combination technique using a remove-restore procedure. In this paper, the EGG96 model is evaluated for the area of Eastern Europe by comparisons with test solutions based on new gravity and terrain data available to the authors and on the new global geopotential model EGM-96. Furthermore comparisons of the quasigeoid models for Eastern Europe with GPS/leveling data and satellite altimetry data from Russian satellites will be discussed.

A REVIEW OF METHODS USED FOR THE ESTIMATION OF HIGH-DEGREE GEOPOTENTIAL MODELS

N. K. Pavlis (Hughes STX Corp., 7701 Greenbelt Rd., Greenbelt, MD 20770, USA)

The development of high-degree geopotential models currently involves two main operations: (1) harmonic analysis of a global datasets of a functional of the field (e.g., gravity anomalies) and (2) the combination of the information obtained from (1) with gravitational information obtained from satellite tracking data analysis. The harmonic analysis step can be performed using: (a) the 'simple' Numerical Quadrature (NQ) technique, or, (b) the Optimal Estimation (OE) technique of Colombo (1981), and more recently (c) a Block-Diagonal technique. A common prerequisite for the implementation of any of these techniques, is the availability of data with global coverage adhering to specific conditions pertaining to geometry and error properties. Depending on the technique used for harmonic analysis, the combination solution can be performed in different ways. The advantages and disadvantages of the various strategies will be reviewed. Special emphasis will be given to the propagated error models resulting from the various techniques.

GRAVITATIONAL POTENTIAL CHANGES OF A SNREI EARTH MODEL TO A POINT SURFACE MASS LOAD

Wenke Sun and Lars E. Sjöberg (*Department of Geodesy and Photogrammetry, Royal Institute of Technology, S-10044 Stockhom, Sweden*)

We study gravity and potential changes of a SNREI earth model to a point surface mass load. we define load Love numbers for any radial distance r, and derive expressions of Green's functions for calculating the vertical displacement, potential and gravity changes for any r, especially on the undeformed and deformed surface of the earth. Numerical calculations are carried out for the 1066A earth model. Load Love numbers are obtained for three depths. The results show that the load Love numbers inside the earth decrease very fast as n increases. The investigation of the load Love numbers inside the earth for degrees 2 and 20 indicates that a low degree load Love number has a global contribution and varies gently in magnitude along the radius. While a high degree load Love number reflects a regional or even a local contribution and it decreases very fast as the depth increases. The Green's functions of vertical displacement, potential and gravity changes for above mentioned three depths are also numerically calculated. An important phenomenon implied by the results is that the whole earth deforms under a surface mass load. Correspondingly, a mass redistribution must happen in the whole earth. Therefore a topographic-isostatic potential model obtained by the loading theory must be composed of all harmonic degrees, from 0 to infinity. The immediate application of this work is to the study of a topographic-isostatic potential model.

A COMBINATION METHOD FOR COMPUTING TERRAIN CORRECTIONS

D. Tsoulis (Institut für Astronomische und Physikalische Geodäsie, Arcisstr. 21, D-80290 München, Germany)

The vertical component of the Newtonian attraction of topographic masses as given by a DTM, can be computed either by means of closed formulas for ideal bodies, e.g. right rectangular prisms, or by means of the FFT technique. In the latter case, a binomial expansion is used, under the precondition that the slope of the terrain does not exceed 45°. In rugged terrain this condition is not always fulfilled, causing the FFT series to diverge in some cases and to converge very slowly in many other situations.
A combination method has been developed which overcomes this problem. The computation area is divided into two zones. The contribution of the inner zone (immediate neighborhood of the computation point) is computed by summation of the effect of individual prisms. The rest of the DTM is treated with the FFT algorithm after a proper modification of the kernel function. Test computations with a data set in the Alps (50x50m grid, area 15x20km) were performed to investigate the efficiency of the method. It was shown, that the convergence of the FFT series is recovered and that the difference between the combination method and the exact prism summation method can be kept below a threshold of 0.02 mGal rms or better.

IMPROVEMENTS IN THE COMPUTATION OF DEFLECTIONS OF THE VERTICAL BY FFT

I.N. Tziavos and V.D. Andritsanos (Department of Geodesy and Surveying, Aristotle University of Thessaloniki, Univ. Box 440, 540 06 Thessaloniki, Greece)

Deflections of the vertical are computed by the effective FFT method using the Vening Meinesz integral formula in spherical convolution form. The gravimetric deflection components are compared with those derived by the planar FFT techniques as well as with observed astrogeodetic components in order to assess the improvements, in terms of accuracy, obtained by the spherical approximation. Moreover, the effect of the deflections directly on the geoid is investigated using new efficient convolution formulas on the sphere. Also discussed is the development of the software used in the numerical tests, and ways of its further improvement by applying alternative formulations, like, e.g., the newly developed Parker's formulas.

EXPLORING THE DETAILED STRUCTURE OF THE AUSTRALIAN GRAVITY FIELD USING FRACTAL AND POWER SPECTRUM TECHNIQUES

K.F. Zhang and W.E. Featherstone (School of Surveying and Land Information, Curtin University of Technology, GPO Box U1987, Perth WA 6001, Australia)

As one of the world's oldest continents, Australia has experienced a complicated geological history and is also highly weathered. As such, the gravity field of Australia behaves differently to that in other countries. In order to show this, three test areas are selected which represent different gravity field and topographic features. Four techniques are used to study the characteristics of the Australian gravity field. These are statistical comparisons, profile analyses, Fourier power spectra and the Hurst fractal dimension. Fourier spectral analysis and the fractal geometry method offer a new paradigm for understanding detailed structure and features of the Earth's gravity field. This study shows that the gravity field of Australia is very complicated and presents an exceptional case in relation to the widely accepted view of gravity field structure. It is revealed that the topography contains longer wavelength features than gravity in many parts of Australia. It is also demonstrated that not one of the free-air, Bouguer or topographic-isostatic gravity anomalies is consistently the smoothest type in Australia, which has implications for subsequent gravimetric geoid determination. This suggests that a combination of these gravity anomalies should be used in gravity field studies, such as the application of the remove-restore technique in gravity gridding prior to geoid determination. There also exist large density contrasts in some regions below the Australian continent, thus demonding a digital density model.

G14 Geodetic and geodynamic programmes of the CEI (Central European Initiative)

Convener: Sledzinski, J.

REGULARIZATION CONTRAINTS ON MASS POINT GRIDS AND THEIR RELATION TO GRAVITY FIELD STOCHASTICS

M. Vermeer (Finnish Geodetic Institute, Geodeetinrinne 2, FIN-02430 Masala, Finland)

In the spectral inversion technique representing the Earth's gravity field by grids of "buried mass points" as implemented in the mgm software, constraints have to be applied to regularize the inversion process and to guarantee a stable and reasonable-looking result. Such techniques, generically known as TIKHONOV regularization, can be interpreted as providing a priori information on the values of (functions of) the mass point values Gmi solved for. We discuss the way this is done in the mgm software, by constraining both the mass point values themselves and inter-neighbour differences, and show how these constraints are related to well-known models of gravity field stochastics such as KAULA's rule and TSCHERNING-RAPP.

JOINT USE OF GPS TECHNOLOGY AND OTHER TECHNIQUES IN ENGINEERING SURVEYING.

J. Bogusz (Institute of Geodesy and Geodetic Astronomy WUT, Warsaw)
M. Korcz (Academy Maritime Ltd., Gdynia)
M. Szolucha (Military Centre of Geodesy and Remote Sensing, Warsaw)

Nowadays there are many applications of combined GPS technology and other techniques (including terrestrial) in engineering surveying. This paper describes the experiment, which was performed on the Silm Lake in Rawa (Northern Poland) by the people from Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology in co-operation with the Academy Maritime Ltd. The main aim was to investigate the usefulness of the particular satellite full kinematic and DGPS techniques referred to the terrestrial observations to evaluate the manoeuvrability of ships according to the international standards, established by International Maritime Organisation. The following Trimble GPS receivers took part in the experiment : two 4000 SSE, one 4000 SST, one 4000 ST with the radio-beacon, two Pathfinders, three Pathfinder Community Base Stations and moreover the terrestrial optolocal system, based on the infrared waves. Major part of this equipment was placed on the exact model of the tanker which swam on the lake. Two techniques of observations were used which could be very useful in determining the position of the moving objects i.e. the full kinematic mode and DGPS observations in both real-time and postprocessing. Comparison of these two techniques and the terrestrial observations from the optolocal system was then performed. The results of the particular experiments are discussed in detail in the paper. They also will be utilised by the Polish Merchant Marine and in construction of the DGPS network in Poland.

PROGRAMME OF THE SCIENTIFIC RESEARCHES ON THE EARTH'S CRUST DEFORMATION REALISED IN ASTRO-GEODETIC OBSERVATORY IN JÓZEFOSŁAW.

J. Bogusz, Jerzy B. Rogowski (Institute of Geodesy and Geodetic Astronomy Warsaw University of Technology, Warsaw)
T. Chojnicki (Polish Academy of Science, Space Research Centre, Warsaw)

Astro-geodetic Observatory of the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology at Józefosław was incorporated in 1991 as the IGS station. Since 1993 the following permanent services have been maintained: GPS observations using Trimble 4000 SSE receiver and TurboRogue SNR-8000, tidal gravimetric observations using LaCoste Romberg gravity-meter model G and astrometrical observations with Zeiss telescope. Regional meteorological data has been also collected since 1993 in co-operation with the Institute of Meteorology and Water Management. For investigation the crustal deformations we computed the GPS position of the IGS point in 3 hours interval, for the same period of time was estimated the influence of the atmospheric loading and attraction effect according to meteorological data (temperature, pressure and humidity from the stations located around the observatory). Also for modern geodynamical observatories the knowledge of local gravitation field is one of the essential requirements. Taking this into consideration, in November 1993 Observatory started tidal observations. Analysis of the data collected during the first three years of activity are presented in the paper. Subject of our study was to find out the correlation between changes of the co-ordinates obtained from different methods of observation and trial of building the tidal and non-tidal models of deformations for the permanent observations performed within the IGS and EUREF projects. The preliminary results of this study are also discussed.

COMPUTATION OF VELOCITIES OF SOME CENTRAL EUROPEAN STATIONS ACCORDING TO DATA PROCESSING OF CEGRN AND EXTENDED SAGET CAMPAIGNS.

J. Bogusz, L. Kujawa, W. Kurka, M. Piraszewski, J. Rogowski, J. Śledziński (Institute of Geodesy and Geodetic Astronomy WUT, Warsaw)
M. Figurski (Military University of Technology, Warsaw)

Two international GPS networks were established in this decade for studying 3D displacement of points located in Eurasian tectonic plate. The first one is EXTENDED SAGET co-ordinated by Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology. Observation campaigns have been organised as an epoch campaigns (occupation time five day) every year since 1992. In the first GPS EXTENDED SAGET campaign participated more than 20 European stations. The second international GPS network was CEGRN (Central European Regional GPS Geodynamic Reference Network) realised in the frame of CERGOP (Central European Regional Geodynamics Project), initiated by the group of Polish and Hungarian scientists in 1992 as a project of the CEI Section C " Geodesy". Zero epoch CEGRN GPS campaign was executed from May 2nd to May 6th, 1994. Observation campaigns were organised every year, occupation time was five day. Results of data processing in ITRF'94 reference frame selected number of EXTENDED SAGET and CEGRN sites using BPE (BERNESE Processing Engine) are presented in the paper. The final results were combined with global IGS solutions obtained from Bern CODE Centre. Velocity vectors of selected stations were analysed and compared with NUVEL NNR 1A velocity model and also with ITRF'94 velocities of selected stations.

LOCAL GEODYNAMICAL RESEARCH INVESTIGATIONS OF THE SUDETY MOUNTAINS AND THE SUDETY FORELAND

J. Bosy, S. Cacon, B. Kontny (Department of Geodesy and Photogrammetry, Agriculture University, Grunwaldzka str. 53, 50-357 Wroclaw, Poland)

Since 1992 some local geodynamic GPS networks was established in Lower Silesia Region (south-west Poland): „Snieznik Massif", „Stolowe Mountains", „Paczkow Through", „Turów", „Geosud" (for connecting all preview networks). The networks were designed and realised by Department of Geodesy and Photogrammetry of Agriculture University of Wroclaw. The results of yearly repeated observations (GPS, gravimetric and levelling) of all of these networks are put into geometrical and physical analyses. Several sites of the local networks were included into international geodynamics projects (CERGOP, EXTENDED SAGET). Geodynamic researches in Sudety Mountains are provided on both, polish and czech sides of the border with Institute of Rock Structure and Mechanics Academy of. Science - Praque and Department of Geodesy of Technical University of Brno.

REPORT ON DAY-TO-DAY GPS DATA PROCESSING PERFORMED BY WARSAW UNIVERSITY OF TECHNOLOGY ANALYSIS CENTRE.

J. Bogusz, L. Kujawa, W. Kurka, M. Piraszewski, J. Rogowski, J. Śledziński (Institute of Geodesy and Geodetic Astronomy WUT, Warsaw)
M. Figurski (Military University of Technology, Warsaw)

Since January 1995 the CODE Processing Centre and the Institute of Geodesy and Geodetic Astronomy of the WUT have entered into co-operation aimed at testing different processing methods for the Polish network consisting of 3 permanent IGS stations. The connection to the global reference frame is realised by processing 4 additional European IGS sites. The results of four different processing strategies were compared with the results achieved by CODE from the global network. The experiment was a practical test of the idea of IGS regional data processing expected for IGS Regional Network Associated Analysis Centre. The report of 100 day-to-day solutions has been presented at the XX IUGG General Assembly in Boulder, Colorado (Rogowski J. and all, 1995). Since January 1996 the WUT Processing Centre (accepted as an IGS Regional Network Associated Analysis Centre - RNAAC WUT and also EUREF Local Analysis Centre - WUT EUREF LAC) has started the systematic processing of network consisting of 13 sites, i.e. Józefosław, Borowiec, Lamkówko, Wrocław, Borowa Góra (Poland), Penc (Hungary), Pecny (Czech Republic), Mendeleievo (Russia), Wettzell (Austria), Kootwijk (Holland), Matsahovi (Finland), Onsala (Sweden) and Matera (Italy). We tested four strategies of solution and we decided to use one of them - ambiguity fixed with using QIF (Quasi Iono Free) strategy and modelling the parameters of ionosphere. Our results are sent to CODE as a contribution to IGS Pilot Project "Densification of ITRF through Regional GPS Analysis" and also to IfAG within the EUREF project. Analysis of the results from 1996 are presented in the paper.

GPS PERMANENT STATION „WROCLAW"

J. Bosy, S. Cacon, B. Kontny (Department of Geodesy and Photogrammetry, Agriculture University, Grunwaldzka str. 53, 50-357 Wroclaw, Poland)

Since November 1996 the new GPS permanent station in Poland was started to work. This is the first one in Lower Silesia Region, located in Wroclaw city, on the epivaristic tectonic platform. The station has been performed by Department of Geodesy and Photogrammetry of Agriculture University of Wroclaw where a few local geodynamic projects are realised. The WROC Station will be one of the reference stations for the local investigation GPS networks in south-west part of Poland.
For the permanent GPS observations the Ashtech Z-XII3 receiver with the Choke Ring antenna (Dorne Margolin ASH) is used. The station is been included now to EUREF and IGS network. Observation data in Rinex2 format are available via Internet on anonymous ftp server of our Department (ftp.geo.ar.wroc.pl. /pub/WROC; 156.17.81.101). Now the special www page is preparing.

THE REFRACTION CORRECTION IN PRECISE LEVELLING

H. Bryś and L.Zielina (Geotechnical Institute, University of Technology ul. Warszawska 24, 31-155 Cracow, Poland)
A. Pachuta (Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology, Pl. Politechniki 1, 00-661 Warszawa, Poland)

A model of differential refraction for levelling is presented. The model considers logarithmic function of the air temperature, air temperature gradient and the height of the line of sight above the terrain. The extreme refraction effect can reach 0.2 mm for one levelling station. The effect may cause a systematic error for the levelling line of big height differences. An electronic gradientometer for measuring the temperature gradients with an accuracy of 0.05 K/m has been constructed. One is able to determine refraction coefficient differing no more than 15% from the model. Field data registration and data processing are done using PSION ORGANIZER LZ64 microcomputer. Proper software has been developed.

Problems of geodetic monitoring at atomic power stations

P. Chernyaga (Ukrainian State Academy of Water Management, Soborna str, 11, 266000, Rivne, Ukraine)

The problem of geodetic monitoring as a part of geodynamic and ecological monitorings of the environment of atomic power stations (APS) is one of the most pressing issues. This includes the system of regular comprehensive and special observation, the assessment of controlling and forecasting processes both on a global and on a regional and local scale. Studies into the geodetic monitoring of APS put forward many scientific, methodological and organizational issues. To qualitatively analyze results of the monitoring of APS we have carried out research including: the creation of the mobile and constructive method to salve problems of forecasting the stability of structures and the movement of the Earth surface, the selection of optimal geodetic methods to determine the setting of structures of their changes during the process of forecasting, the setting up of the method to process results of geodetic measurements of various epochs with the characterization and evaluation of the state of structures of the whole complex, the consideration of the impact of electric magnetic fields upon geodetic measurements, the research into perspectives of the rational nature use in the regions of APS on the basis of geodetic monitoring. Such studies will give the possibility to set up the scientific and methodical basis for geodetic observations and to generalize materials for whole complex.

TECTONIC PATTERN OF THE SAGET-PROJECT APPLIED TO THE CERGOP-PROJECT

Krystyna Czarnecka, (Institute of Applied Geodesy, Warsaw University of Technology, Plac Politechniki 1, PL-00661 Warsaw, Poland)

Paper is aimed at answering the question in which extension the model of geodynamics of the SAGET-project can be useful for the CERGOP geodynamical project of the CEI countries. The role of Trans European Suture Zone (TESZ) and heterogeneous tectonic structure of the European continent as well as differentiated geodynamical features of its northern and southern parts are discussed. Earth crust density, crust thickness, heat-flow and maximum horizontal stress pattern are analysed. Preliminary guiding rules for sub-regional geodynamical projects in the frame of CERGOP are submitted as a conclusion.

University Education Standards and their Importance for the CEI-Countries

Kazimierz Czarnecki (Warsaw University of Technology, Institute of Geodesy and Geodetic Astronomy, 00-661 Warsaw, Poland)

A Working Group on University Education Standards has been established by the CEI Section C "Geodesy" in 1994.
General analysis of the educational models in Central Europe as well as the aim of the WG and its task are presented. A need of multidisciplinary cooperation in education of geodesists is pointed out. A brief report of the WG current activities and future plans are submitted.

RADIONAVIGATIONAL DGPS SYSTEM FOR THE SAFETY OF NAVIGATION IN WEST POMERANIA

A. Dolgopolow (Urząd Morski, Plac Batorego 4, 70-207 Szczecin, Poland)
A. Wolski (Maritime University, Waly Chrobrego 2, 70-500 Szczecin, Poland)

The port of Szczecin is linked with the Baltic Sea by a 65-kilometre fairway for deep-sea going ships. In order to maintain the safety of navigation on the fairway for deep drawing ships hydrotechnical and dredging work has to be continually carried out. Increased accuracy of bathymetric and dredging work requires accurate methods of position plotting. This can be provided by establishing a local DGPS reference station emitting differential corrections.
In 1996 an experimental DGPS reference station was set up which transmits differential corrections on VHF channel 87. This work presents an analysis of data from measurements that in a specific area aimed at determining the following: availability of differential corrections and satellite signals, stability and accuracy of plotting static and dynamic positions. The study has shown that the reference station has been correctly located and is extremely useful in such applications as hydrotechnical and geodesic work, maritime salvage and data gathering for the GIS system.

AUTOMATION OF THE PROCESSING GPS OBSERVATIONS IN CASE OF THE PERMANENT GEODYNAMIC STUDIES

Jan Douša (Czech Technical University, Department of Geodesy, Thákurova 7, Prague 6, 166 27, Czech Republic)

In geodynamic studies, the number of applications of GPS technology is growing up rapidly. The projects are often designed as permanent GPS networks which require the continuous processing of data. Using the Bernese GPS Software, convenient especially for high accuracy campaigns, gives very good possibility to automate all permanent processing. The system can be even enriched by individual superstructure. The example stemming from automation of the processing of EUREF permanent GPS network is given.

THE CENTRAL EUROPE REGIONAL GEODYNAMICS PROJECT (CERGOP): FIRST RESULTS AND FUTURE PERSPECTIVE

I. Fejes (FÖMI SGO, P.O.B. 547, H-1373 Budapest)
D. Ghitau (Hochschule für Bauwesen, Bd. Lacul Tei 124,RO- Bucuresti)
C. Marchesini (Università di Udine, via Cotonificio 114, I-33100 Udine)
M. Mojzes (Slovak Tech. University, Redlinskeho 11, SK-81368 Bratislava)
P. Pesec (Institute for Space Research, Lustbühelstraße 46, A-8042 Graz)
E. Reinhart (IfAG,Richard Strauß Allee 11, D-60598 Frankfurt/Main 70)
J. Simek (VUGTK GO PECNY, CZ-25165 Ondrejov)
J. Sledzinski (WUT, Pl. Politechniki 1, PL-00661 Warsaw)
F. Vodopivec (FAGG, Jamova 2, SLO-61000 Ljubljana)
F. Zablotskij (Lviv Polytechnic, Bul. S. Banderi 12, UKR)

Initiated during the 1993, CERGOP was supported by geodesists of Austria, Croatia, Czech Republic, Germany, Hungary, Italy, Poland, Romania, Slovakia, Slovenia, Ukraine, in order to install a reference geodetic network in the Central Europe for geodynamic investigations. The reference network (CEGRN) consist of 31 points distributed in 11 countries and until now it was measured three times with GPS receivers. The network serves also as a regional reference frame for local geodetic networks. An extension of the project to the other countries of the Balkan peninsula is foreseen.

GPS MEASUREMENTS ON THE ROMANIAN TERRITORY FOR THE ASSESSMENT OF TECTONIC CRUST DEFORMATIONS

D. Ghiţău (Civil Engineering University of Bucharest - Geodesy Research Group, 72 305 Bd. Lacul Tei 124, Bucharest-2, Romania - **GFUBB**)
F. Rădulescu (National Institute for Earth's Physics, PO Box MG-2, Bucharest-Măgurele, Romania - **INFP**)
E. Reinhart (Institute of Applied Geodesy, Richard-Strauss-Allee 11, Frankfurt a.M., Germany - **IfAG**)
V. Roşca (Geological Institute of Romania, 78 344 Caransebeş Street 1, Bucharest-1, Romania - **IGR**)

Since 1994 Romania joint 10 other countries of central and east Europe for an interdisciplinary research programme developed as the *Central Europe Regional Geodynamic Project* (**CERGOP**). With an important technologic aid offered by IfAG, Romania took part to the 1995 and 1996 **CERGOP - GPS** campaigns, with 4 points, included into the initial Project network. The territory of Romania is shared by 3 geotectonic realms and for a better coverage of each realm, following a proposal made by the Romanian researchers, 4 other points were added to the initial sites, i.e. an 8 points array. Given the strong seismicity of the Romanian territory, it is suggested that the number of points should be increased to 20, in order to improve the reliability of the **GPS** deformational information. The lay out of the 20 **GPS** points network is shown together with geological arguments for the positioning of each group of new points

REFERENCE FRAME FOR KINEMATIC INTERPRETATION OF CEGRN OBSERVING CAMPAIGNS

J. Hefty, (Department of Theoretical Geodesy, Slovak Technical University, Radlinského 11, 813 68 Bratislava, Slovakia)

Well-defined reference frame for geodynamic investigations in Central Europe should compensate the global horizontal motion of the Central European part of the Eurasian Plate and at the same time should enable to resolve the intraplate motion of monitored sites. Proposed realisation of reference frame for kinematic interpretation of repeated GPS epoch campaigns in Central Europe uses as fiducial points seven European ITRF sites (Borowiec, Graz, Kootwijk, Matera, Onsala, Wettzell and Zimmerwald) with long-term history of space geodesy observations. ITRF94 coordinates and ITRF94 velocities reduced for the Eurasian plate motion model according to NNR-NUVEL1A define the CERGOP Terrestrial Reference Frame - CTRF. Application of CTRF is demonstrated on comparison of CEGRN campaigns from 1994, 1995 and 1996. Differences in horizontal coordinates up to 0.015 m are observed. The derived coordinate differences are reliable only when the fixed configuration of CTRF fiducial sites is used for referencing of all CEGRN campaigns. Analyses of covariance matrices of transformed points show that the uncertainties are increasing for the south-east part of the CEGRN network. CTRF is suitable also for kinematic interpretation of national geodynamic GPS campaigns and for comparison of the sites identical with CERGOP sites.

ESTABLISHMENT OF THE INTERNATIONAL GEOPHYSICAL STATION PIP-IVAN (2022 M) IN EASTERN CARPATHIANS

J.Iwankiv (West Centre of the Ukrainian Academy of Sciences, Lviv)
A.Dultsev, F.Zablotskij, K.Tretiak (State University "Lviv Polytechnic", Lviv)
J.Śledziński (Institute of Geodesy and Geodetic Astronomy WUT, Warsaw)

The GPS satellite techniques are widely used for investigation of the recent tectonic crustal movements in the seismic region of Eastern Carpathians. Some international geodynamic projects such as CERGOP, EXTENDED SAGET, GEODUK cover this area. There is also an urgent need to establish in this region a permanent geophysical station that could collect permanently satellite, tidal gravimetric, seismic and other observation data. As the best solution for such a station it was considered a reconstruction of an astrometeorologic observatory at the Mount Pip-Ivan (2022 m a.s.l) in Czarnohora. This station was designed and built in 1936-1938 by Polish constructors and contains a main building with 43 rooms and a meteorologic platform, an astronomic pavilion of a shape of a dome of the diameter 14 m. This station has not been used since the time of the second world war. In October 1996 a scientific-technical Ukrainian-Polish conference on reconstruction of the Pip-Ivan Observatory was held in Yaremche. The local administration authorities of the Ivano-Frankiwsk region, heads of the West Centre of the Ukrainian Academy of Sciences as well as many leading scientists from Ukraine and Poland have decided to resume the activity of the Observatory as an Ukrainian-Polish (international CEI) scientific institution. Several permanent working laboratories and other comfortable facilities for scientific work, rooms for international conferences will be reconstructed. The paper gives some more details of the proposed activities of the Pip-Ivan Observatory.

STUDY OF THE INFLUENCE OF INDIRECT EFFECT OF OCEAN TIDES AND OF DIRECT DEFORMATION EFFECT OF ATMOSPHERE ON THE RESULTS OF THE GPS OBSERVATIONS

J. Kostelecký (Research Institute of Geodesy, Topography and Cartography, CZ - 250 66 Zdiby 98)
A. Zeman (Faculty of Civil Engeneering, Czech Technical University, CZ - 166 29 Prague 6)

Purposes of this presentation is to determine the influences of the indirect effect of the ocean tides and direct deformational effect of the atmosphere on the results of the GPS observations, performing on the stations GOPE (Czech Republic), Wettzell (Germany) and Graz (Austria) and also for the Central EUROPE Regional Geodynamic Project (CERGOP) GPS stations in the region of the central and east Europe. On base of analyses and the results it is possible to state that for present accuracy of GPS observations is the influence of ocean loading and atmospheric pressure effects for geodynamic campaigns on the extent of the region of the Czech Republic negligible. For the campaigns on the territory of greather regions (i.e. central Europe) will be necessary to apply the atmospheric corrections to height differencies. These corrections, however, due to periodicity have negligible influence on the secular changes.

A TECHNIQUES FOR CREATION OF MAPS OF CURRENT GRADIENTS OF EARTH CRUST VERTICAL SHIFTS

V.M.Koukharskyi, Ya.G.Savula(Dept. of Applied Mathematics , I.Franko Lviv State University,Universitetska 1. Lviv, Ukraine, 290602)
K.R.Tretiak(State University "Lviv Politekhnik", Bandera str. 12. Lviv, Ukraine 290646)

At present the problem of repeated geodesic levelling processing with the aim of realistic representation of deformation processes of endogenous origin is very important. The traditional maps of current vertical shifts of earth crust (CVSEC) are based on one leveling point. The precision of shift vectors on the maps of earth crust vertical shifts gradients/deformations/ (CGECVS)is independent of the distance to the original place, network geometry, and depends on measurement errors in leveling nets. Regardless of different physical interpretations of deformation processes by CGECVS and CVSEC maps, the CGECVS maps will be more accurate than the CVSEC maps. With the aim of maximal realistic representation of deformation processes we propose a technique for vertical shifts gradient interpolation, which is based on Least Square Method and Finite Element Method. The combination of these methods allows us to employ elementwise interpolation. According to this approach we begin to interpolate first on the element with the greatest number of measurements and where information is most accurate. It is evident that, interpolation, which begins on most investigated regions,must give a more accurate CGECVS map than traditional measurement averaging on certain tectonic blocks.

A CONTRIBUTION TO THE STUDY OF MODELLING OF THE TROPOSPHERE BIASES OF GPS OBSERVATIONS WITH HIGH ACCURACY

D. Landsperský and L. Mervart (Czech Technical University, Department of Geodesy, Thákurova 7, 166 29 Prague 6, Czech Republic)

Propagation delays of GPS code and phase signals caused by the neutral part of the atmosphere, tropospheric refraction, are being considered the most limiting factors for high accuracy GPS geodynamical and geophysical applications. This effect most influencing the vertical part of results, the derived station heights or height-differences, requires appropriate and efficient modelling. For empirical testing, Bernese GPS Software was applied. It allows the use of several a priori models for tropospheric refraction, and more estimation of corrections relevant to the model in the general GPS parameter estimation process. Using the high accurate IGS orbit data, the impact of introducing the azimuth-dependent tropospheric parameters is studied.

VELOSITY MAPS OF MODERN VERTICAL DEFORMATIONS OF THE EARTH SURFACE OF THE UKRAINE MOUNTAIN SYSTEMS

E.Lebedeva, K.Tretyak, O.Smirnova (State University "Lviv Polytechnic", Bandera str. 12, 290646 Lviv, Ukraine)

The development of the velocity map of vertical deformations of the earth surface in Carpathian and Crimean regions was carried out in four stages: 1) - selection of the levelling results, 2) - calculation of gradients of the earth surface vertical deformations by the results of different epochs, 3) - mutual balancing of the meaning of the different epochs gradients, taking into consideration the bench marks resistance, 4) - interpolation of isolines of the vertical deformations gradients.The networks of highly precised levellings cover the earth surface of the studied regions irregularly. At the Carpathians territory the levellings were done in 1890-1993, and in the Crimean peninsula - in 1946 - 1991.The balancing of the deformations calculated velocities during different epochs was done by parametric method, taking into consideration the geomorphological "weight" of the bench marks resistance. For the interpolation of the vertical deformations isolines the optimal interpolating radius was udes. By the results of interpolation the velocity maps of modern vertical deformations of the earth surface in Carpathian and Crimean regions with scale 1:500 000. The ranges of the deformations velocities for Carpathian region are in the limits (+15 - 12)*10^{-8} , and for the Crimea - (+350 -400)*10^{-8} year .The zones of anomalous deformations of the regions earth surface were established and the correlation of them with tectonical structures was done.

QUALITY MONITORING OF GEODETIC SITES IN THE CENTRAL EUROPEAN GEODYNAMIC REFERENCE NETWORK

Pál Lévai (FÖMI Satellite Geodetic Observatory, P.O. Box 546, H-1373 Budapest, Hungary)

The Central European Regional Geodynamics Project (CERGOP) - participated 11 countries - has been started since 1995. The main objectives of the project are to integrate geodynamic research, to investigate geotectonic features and to provide a stable reference frame for deformation studies based on the Global Positioning System (GPS) measurement techniques in the Central European region. The base of the project is the Central European Geodynamic Reference Network (CEGRN). The reliability of the CERGOP results depend on the quality of this network and of course on the points of the network. The CEGRN consists of 31 regular and 7 associated sites. A study group was formed to check the sites in a systematic and objective way in accordance with the CERGOP network design and site monumentation requirements. In this paper the methodology and the sites inspections results are shown and the CEGRN Site Catalogue is introduced which is partly available on the INTERNET.

DIFFERENTIAL AND INTERFERENTIAL GNSS FOR PRECISE NAVIGATION AND ROAD SURVEY

Manzoni Giorgio - University of Trieste, Italy
Cefalo Raffaela - University of Trieste, Italy
Skerl Gilberto - University of Pisa, Italy
Manzoni Marco - geophysicist
Peressi Gabriele - geophysicist
Zini Mario - geophysicist

The University of Trieste has experimented several applications of differential and interferential GPS to determine the trajectories of aircraft and terrestrial vehicles carrying geophysical and geometrical sensors. Experiments and analysis with centimetric accuracy have been carried out on data collected in different environments. Recently, absolute and differential GPS+GLONASS has successfully been tested for navigation and quick surveys. Moreover, a novel EDM+GPS method for quick road survey with centimetric accuracy has been experienced.

ABSOLUTE GRAVIMETRY IN CENTRAL EUROPE: THE ITALIAN CONTRIBUTION

I. Marson (DINMA, University of Trieste, Via Valerio 10, 34127 Trieste),
G. Cerutti (IMGC, CNR, Strada delle Cacce 75, 10173 Torino, Italy)

Absolute gravimetry plays an important role in geodetic and geodynamic programs. In geodesy, and particularly in geodetic metrology, absolute gravimetry is widely recognized as the fundamental tool to define the gravity datum and the gravity scale. This information is important to merge the several gravity data banks into a unified gravity system, to compute gravity anomalies for geophysical prospections across different countries, to compute a worldwide geoid for cartography and so on. In geodynamic, absolute gravimetry plays a relevant role in the study of the long period components of the geodynamical process. Since an absolute gravimeter measures the gravity acceleration by means of direct measurement of space and time, and it is theoretically free from drift, it is the only tool able to detect the long term gravity variations due to crustal deformations and eventually mass or density changes within the Earth. The components of shorter periods can be detected by means of superconducting gravity meters. The simmetrical rise-and-fall instrument developed by the Italian Metrological Institute G. Colonnetti, CNR, Torino, is involved in gravity projects aimed at the establishment of absolute gravity in Central Europe. This paper discusses the projects and the results achieved so far.

BERNESE 4.0 - AN EFFICIENT TOOL FOR PROCESSING GPS MONITORING DEFORMATION NETWORKS

L. Mervart (Institute of Geodesy, TU Prague, Czech Republic)
M. Rothacher (Astronomical Institute, University of Berne, Switzerland)

Number of control GPS networks used for monitoring of crustal deformations increased rapidly during several past years. GPS technology provides a sufficient accuracy to fulfill this task. Very important task is the development of sophisticated algorithms for processing of data. Bernese GPS Software Version 4.0 represents a very efficient computing tool. The paper deals with the usage of this software package and an automation of the processing by the so-called Bernese Processing Engine. The examples stemming from the CEGRN-96 Campaign are presented.

DETERMINATION OF DEFLECTION OF THE VERTICAL USING TOTAL STATION INSTRUMENTS.

Tomasz Olszak (Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, Warsaw)

Determination of deflection of the vertical is one of the most important tasks of the geodesy. The increased role of the satellite GPS positioning techniques gives nowadays the possibility of a new approach to this problem. The astronomic measurements play also a decreasing role in establishment of astro-geodetic control networks.
The paper presents results of the determination of deflection of the vertical based on a combination of the GPS technique and astronomic measurements made by the electronic theodolite Total Station. Instrument Total Station LEICA TC2002, combined with the automatic time keeper and automatic registration of circle readings in field organiser PSION, measures the astronomic azimuth and the astronomic latitude. Combining these measurements with GPS measurements of the azimuth an geographic latitude referred to the ellipsoid we can determine the deflections of the vertical from the Laplace equation.

DGPS NAVIGATION SYSTEMS IN CENTRAL EUROPEAN COUNTRIES

Stanisław Oszczak (Institute of Geodesy, Olsztyn University of Agriculture and Technology, 10-957 Olsztyn, Poland).

The information on some applications of DGPS methods to marine, aviation and land navigation purposes in Central European Countries is given. The unification and standardization problems is underlined to be compatibile with European projects such as: GNSS-1, EGNOS, MAGNET as well as other global DGPS systems.
The status of projects and problems of creating of DGPS permanent reference stations network in Central Europa is described. The impact of DGPS/DGLONASS integration to give availability, integrity and accuracy for navigation determinations is also presented.

LIMITING SOURCES OF THE PRECISION LEVELLING ERRORS

P.V. Pavliv (Ukrainian State University of Forestry and Wood Technology, General Chuprynka str. 103, 290057, Lviv, Ukraine)

New methods of refraction influence consideration, which we have worked out, make it possible to reveal the action of the earlier unaccounted for sources of precision levelling errors. The aforesaid action reveals itself in a systematic change of the spot height of the soil surface where levelling was carried out. The analysis done has shown that the values of such changes of height s is pre-conditioned by physical properties of soils and their reaction to the action of temperature and humidity changes. Further analysis of the technogical process of a precison levelling has shown that the mechanism of the temperature factor action takes place in two directions under the action of a day and seasonal temperature changes. The analysis done has shown that in the first half of a day levelling is carried out in the period of minimum, and in the other half - in the maximum temperature changes of a day cycle. Taking into account this circumstance it is recommended to lay out levelling routes in the direct and reciprocal directions simultaneously. To minimize seasonal influence it is necessary to carry out repeated levelling of the same line area at the same season. Otherwise, it is necessary to carry out preliminary and repeated levelling in the same period of a year with direct or indirect consideration of soil temperature. The analysis of production materials done has shown that a temperature factor reveals itself most sharply on stone and rock soils and can pre-condition vertical displacements up to tens of millimetres. At the same time loess soils of a partially-wooded steppe zone much more react to moisture and can stipulate vertical displacements up to a few millimetres.

THE INVESTIGATION RESULTS OF MODERN HORIZONTAL DEFORMATIONS OF THE EARTH SURFACE IN CRIMEAN GEODYNAMICAL PROVING GROUND.

I.Romanyshyn, K. Tretyak, (State University "Lviv Polytechnic", Bandera str.12, 290646 Lviv, Ukraine)

The systematic network of Crimean geodynamical proving ground was created in the territory of a mountain part of the Crimean peninsula, near the town of Alushta and occupies the area 400 sg.km. The network has 19 stations ,which are located on the neighbouring peaks. In 1974 and 1977 two repeated cycles of the distance-measurement observations were made by a light-distance-meter "Quartz". The measurements were done along 48 lines in the straight and opposite directions.The lengths of the lines were in the limits 2.8-12.7 km., and the average differences of them of the first and the second cycles reached 2-3 cm. The balancing of measurements in 1974-1977 were done jointly by parametric method according to the differences of the measured lengths in two cycles of observations. By the results of balancing there were calculated the components of deformations of relative displacement by coordinate axes, dilatation and relative rotation of the network elementary triangles. Velocities of the relative total dislocation are in the limits (+0.8-+11.9*10^{-6} 1/year), of dilatation (-7.1-+6.7*10^{-6} 1/year) and of relative rotation (-3.4-+3.4" 1/year) . Anomalous deformations ,which are described by all the deformations components,are concentrated in the southern and north-eastern parts of the network. The total dislocation of the proving ground southern territory is directed to the south and the south-east and coincides with the dislocation direction of the folded structure of Tuaksk anticlinorium, that may witness to preserving the tendencies in tectonical development of this region.

EFFECT OF GRANULARITY ON FINAL RESOLUTION OF TONE IMAGE OF A GEODYNAMIC MAP

B. Pastusiak (Technical University of Szczecin, Al. Piastów 50, 70-311 Szczecin, Poland)

Printed tone maps developed from aerial or satellite photographs provide a valuable source of information for geodynamic, geodesic and other research. What constitutes a problem is evaluation of the effect of granularity on final resolution of the tone map image. An original method for the evaluation of tone transfer in printing without the use of screen is proposed. Moreover, it is pointed how to evaluate the transferred tone depending on a printing plate used, on its roughness in particular. Suitable tests were copied onto the plates whose roughness had been measured (by a profile gauge Talysurf 10). The tests consisted in linear sinusoidal amplitude lattices made on holographic plates by Agfa Gevaert. The lattice constant varied from 50 to 200 lines per one millimetre. The copied tests were analyzed in an optimal system using He-Ne laser light (wavelength $\lambda = 0.6328$ μm). The analysis allowed to determine the density of copied lines and their contrast. Such evaluation enables to choose, from among a variety of plates available on the market, the plate best suited for yielding top quality with a given technology. It also provides for the repeatability of the process in high-circulation printing.

THE IMPACT OF PERMANENT GPS STATIONS FOR REGIONAL GEODYNAMIC INVESTIGATIONS IN CENTRAL EUROPE AND THEIR RELATION TO INTERNATIONAL PROGRAMMES

P. Pesec (Institute for Space Research, Austrian Academy of Sciences, Lustbuehelstrasse 46, A-8042 Graz, Austria)

The task of permanently recording GPS-stations is to place at disposal various types of data and products for different applications. Basic research concerns the definition of a terrestrial reference frame for all kinds of surveying and for global and regional geodynamic investigations. In particular,continuous observations allow for separating seasonal and other unmodelled effects from secular motions caused by movements induced by crustal dynamics. The project CERGOP of the Central European Initiative aims at the establishment of an array of about 50 well distributed stations in up to 16 countries which support global and continental crustal motions monitoring and act as the basis for local geodynamic investigations. The paper explaines the importance of continous monitoring stations for global and regional applications, the role of CERGOP as a driving force for promoting such stations, and the present and future interdisciplinary aspects which can be attributed to those stations, especially for environmental monitoring and research.

ACTIVE DETERMINATION OF THE PLUMB LINE DEFLECTION BY ASTRO-GEODETIC METHOD

S. Savchuk , Oksana Zhylyuk (State University "Lviv Polytechnic", S. Bandera Street 12, 290646, Lviv, Ukraine)

The determination of the plumb line deflection (ξ,η) is the essential problem solution element of creation and utilisation of various geodetic coordinate systems. One of the most known and accurate (0.1-0.3") methods is the astro-geodetic method. The essence of this method is based on the comparison of geodetic B,L and astronomic φ, λ coordinates $\xi=\varphi-B$, $\eta=(\lambda - L)\cos\varphi$.
Nevertheless, the efficiency of this method is still low in comparison with the astronomic gravity measuring method and inertial and space geodesy one. If the accuracy allowances are not rigorous ξ ,η (1-1.5"), especially in site geodetic engineering, the astro-geodetic method may be widely used, if appropriately prepared. The methodology of astronomic coordinates φ, λ, determination is presented in this paper. The geodetic coordinates B,L are determined fromGPS-observations.The mutual determination φ, λ, technique on the measured zenith distances of n stars in the different verticals using optical-electronic theodolites is taken as fundamentals. The software for preparation,performance and processing of astronomic observations automatization is developed.
The experimental investigations were carried out with the goal to check up the efficiency of software and assessment of astronomic determination accuracy. The proposed astronomic observations and plumb line deflection determination method is founded to be effective in accuracy and speed.

THE CURRENT STATUS AND PERSPECTIVES OF EUREF

H.Seeger , P.Franke, H. Habrich, W.Schlüter and G.Weber.
Institut für Angewandte Geodäsie, Frankfurt and Wettzell

In 1987/88 the IAG EUREF Subcommission in close connection to CERCO Working Group VIII on Geodesy designed and defined a new precise geocentric Continental Reference System for Europe (ETRS). The project was performed in 1989 for Western Europe. Starting in 1991 several countries in Central and in Eastern Europe were connected to the ETRF: the three Baltic States, Poland, the Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Romania, Bulgaria and Macedonia as well as Cyprus and Malta. After this work-load is completed, the whole of Europe except Russia, Belorussia, two of the former Yugoslavian States and Albania are combined within one precise Geocentric Reference System which fulfills all the supernational requirements of the European Union.
The paper includes a description of the total project, of the results obtained up to now and of the current and future developments.

CENTRAL EUROPEAN INITIATIVE (CEI) ORGANISATION AND PROGRAMME OF THE INTERNATIONAL COOPERATION IN GEODESY AND GEODYNAMICS

Janusz Śledziński, International Coordinator of the CEI Section C "Geodesy". (Warsaw University of Technology, Institute of Geodesy and Geodetic Astronomy, Pl. Politechniki 1, 00-661 Warsaw, Poland)

The organisation Central European Initiative (CEI) was founded in 1989 as QUADRAGONALE and then developed through PENTAGONALE and HEXAGONALE to the Central European Initiative (CEI).Sixteen European countries are now members of the CEI. The broad programme of geodetic projects and geodynamic research realised in the cooperation within CEI is outlined in the paper. The programme of cooperation include three themes: (a) Interconnection of geodetic control networks in Central Europe, (b) GIS/LIS systems and (c) The geodynamic investigations. The interconnection of geodetic networks is performed by organisation of the EUREF GPS campaigns and acceptance of the ITRF/WGS systems contributing to the unification of a geodetic system in Central Europe. The network of permanent GPS stations is also being established in CEI countries. The main aim of the geodynamic Project CEI CERGOP (Central Europe Regional Geodynamics Project) is to provide a precise geodetic frame for studies of geodynamics of Central European area. The work of ten scientific CERGOP study groups covers the particular areas of application of GPS techniques to geodynamics. The active work of a Section C Working Group on University Education Standards is also outlined. The near-term plan of actions of the CEI Section C "Geodesy" is also given.

RESULTS OF CEGRN'94-96 OBSERVATION CAMPAIGNS

G. Stangl, N. Fachbach, J. Kostelecky, L. Mervart, A. Kenyeres, A. Simon, M. Marjanovic, J. Hefty, L. Gerhatova, J. Rogowski, M. Piraszewski, L. Kujawa, M. Figurski.

Central Europe Regional Geodynamics Project (CERGOP) was initiated by the group of Polish and Hungarian scientists in 1993 as a project of the CEI Section C "Geodesy". Nowadays one important contribution of this project is establishment of a Central European GPS Reference Network (CEGRN) as a tool of the practical realisation of the common reference frame for geodynamical studies in Central Europe. Zero epoch CEGRN GPS campaign was executed in 1994 and was followed by other two campaigns in 1995 and 1996. Three CEGRN observation campaigns were independently processed by the following CERGOP Processing Centres:

* Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, Poland,
* Institute of Space Research AAS, Graz, Austria,
* FOMI Satellite Geodetic Observatory, Penc, Hungary,
* Department of Theoretical Geodesy of the Slovak Technical University, Bratislava, Slovakia,
* IfAG, Leipzig, Germany,
* Research Institute of Geodesy and Cartography, Ondrejov, Czech Republic

The individual solutions obtained from six Processing Centres for 94, 95 and 96 observation epoch are presented in the paper. Combined solution prepared by ISR Processing Centre Graz is also discussed. The recent accuracy of 5-10 mm looks promising for detection of small tectonic movements in the Central European region.

RECENT RESEARCH IN GEODESY AND GEODYNAMICS IN THE CZECH REPUBLIC IN CONTEXT OF CURRENT EUROPEAN PROJECTS

J. Šimek (Research Institute of Geodesy, Topography and Cartography, Geodetical Observatory Pecný, CZ - 251 65 Ondřejov 244, Czech Republic)

After a brief introduction to the institutional background a review is given of the recent activities and results related to the establishing of the Czech National Geodynamical Network, implementation of the ETRF-89 in the Czech Republic, investigation of detailed gravity field by combined terrestrial and satellite methods and geopotential testing. A concept, structure, and function of the Czech IGS station GOPE (Geodetic Observatory Pecný) is presented. Relations of national activities to some current and pending European geodetic and geodynamical projects, like EUREF, EUVN and CERGOP are outlined.

RESULTS OF CEGRN'94-96 OBSERVATION CAMPAIGNS

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THE RESULTS OF THE INVESTIGATIONS OF THE EARTH'S SURFACE HORIZONTAL DEFORMATIONS ON THE CARPATHIAN GEODYNAMIC POLYGON

K. Tretyak, F. Zablotskyj, A. Ostrovskyj, (State University "Lviv Polytechnic", Bandera str. 12, 290646 Lviv, Ukraine)

Investigations of the horizontal motions of the earth crust in the Carpathian region were begun in 1969 by the creation of the space geodetic net on the southern slope of the Ukrainian Carpathians. They cover a part of the Flysch Carpathians, Peninian zone, the Transcarpathian inner flexure. This net was thickened by means of the local net points in 1974. The cycle of light distance measurements were performed in 1972 on this space geodetic net, the cycle of GPS measurements - in 1993 within of the "GEODUC'93" International campaign. The cycles of light distance measurements on the local net were performed in 1974, 1975 and in 1994. The components of the Earth's surface deformations were calculated after the results of the measurements. The analysis of the distribution of the deformation parameters determined that the territory of the region may be conventionally divided into two blocks: the northern block and the southern one. The mean velocities of deformation accumulation per year make up: from $-0.9*10^{-7}$ to $-2.8*10^{-7}$ for the northern block, from $+0.8*10^{-7}$ to $+2.3*10^{-7}$ for the southern block. The direction of the motion of these blocks and their deformations coincide with the geodynamic theory of development of the Carpathians.

ANALYSIS OF TIDAL OBSERVATIONS OBTAINED FROM TWO GRAVITY METERS WORKING SIMULTENAOUSLY.

Tvtus Witkowski (Institute of Geodesy and Geodetic Astonomy of the Warsaw University of Technology Politechniki Sq. 1, 00-661 Warsaw, Poland).

Accuracy of position determined by all-day GPS observations is now on the level of a few centimetres. In order to increase the precision of these observations we have to improve a tidal model of the Earth's crust.
Therefore the continuous gravimetric measurments using two LaCoste&Romberg gravity-meters model G and D have been initiated in Astrogeodetic Observatory of the Institute of Geodesy and Geodetic Astonomy of the Warsaw University of Technology.
The data recording is performed in two ways: using the digital PC registration using the ADC (Analog to Digital Converter) and using analog pen-recorder. The digital maeasurment time amounts to 40 seconds and the intervals between measurments are 15 minutes.
Comparison of results from two models of gravity-meters and computed tidal deformation parameters are described in the paper.

POLISH ABSOLUTE BALLISTIC GRAVIMETER ZZG

Z.Ząbek (Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology, Pl. Politechniki 1, 00-661 Warszawa)

The first model of the ballistic gravimeter ZZG was constructed at the Institute of Geodesy and Geodetic Astronomy in 1993. The paper presents its improved version. The instrument uses symmetrical rise-and-fall method. The observed height of the rise (or fall) of the reflector equals to 20 cm. The catapult is made from rubber cord. The instrument is equipped with a movable corner cube reflector reflecting the light beam from three external mutually perpendicular glass surfaces coated with aluminium. A reference corner cube reflector is suspended on a long-period compensation device absorbing effects of microseismic movements. Additionally, an active piezoelectric compensator of vibrations is applied. The instrument is equipped with vacuum chamber, two-stage rotary vacuum pump, two zeolite absorbers (0.02Pa), He-Ne Zeeman laser, quartz oscilator compared to the stationary rubid standard. Total weight of the gravimeter including supplementary devices does not exceed 120 kg. In 1995-1996 we have made measurements at the Absolute Gravity Basestation Network Pecny (Czech Republic) as well as Modra and Ganovce (Slovakia). The results are compared with measurements made by FG5-107, FG5-101 and JILAG-6 gravimeters. The standard deviation is estimated as 5 μGals.

PROGNOSTICATION OF THE EARTH'S POLE MOTION

O. Zablotska , S. Savchuk (State University "Lviv Polytechnic", Bandera str. 12 , 290646 , Lviv , Ukraine)

The motion of the Earth's poles provokes the change of the geographic coordinates and influence on the determination of precise time . To reduce the astronomical observations to the mean pole it is necessary to know the coordinates of the pole and the difference between Universal and Coordinative times on the date of the observation . These data are published in special bulletins with a considerable delay in time . The worked out software provides the reduction of latitude , longitude and azimuth to the mean pole . The rated accuracy of prognostication of pole's coordinates x , y and UT1-UTC correction for problems of geodetic astronomy is determined as 0.08" for latitude , 0.019" for azimuth , $0.003^{S}\cos\phi$ for UT1-UTC . With the introduction of reduction the obtained errors of prognostication of pole's coordinates will result in the corresponding errors , the latter being less than mean quadratic errors of astronomical determinations . For determination of the UT1-UTC correction by means of approximative polynomial were determinated by Gauss method. The difference between prognostication UT1-UTC correction and bulletin correction characterises the precision of the prognosis . Prognosticated UT1-UTC correction with error $<0.003^{S}\cos\phi$ for the period up to 3 months was received . For the increase of prognosis period the residual values of prognostic function were approximated by means of Furier's rows and the satisfactory results were obtained .

MATHEMATICAL MODELING OF THE RECENT EARTH'S SURFACE VERTICAL MOTIONS OF UKRAINE.

E.Zablotskyj, R.Demus, K.Tretyak (State University "Lviv Polytechnic", Bandera str. 12, 290646 Lviv, Ukraine)

The tectonic blocks differentiation with the typical intensity of the recent vertical motions was carried out with the purpose of modeling and of reliable representation of the Earth's surface kinematics of Ukraine. The statistic analysis of the vertical motions of the fields permited to define the criterions of the regulation of their digital models. The optimum approximate surfaces created by Furier's rows are sunonymously in keeping with these models. The functions of the approximate polynomial coefficients depending on the coefficients of regulation were determined after the treatment results of the digital models of the recent Earth's surface vertical motions of the Ukrainian different regions. The systematization of dependence of the main tectonic structures from intensity of the recent vertical motions obtained after the results of the second geodetic levelling was maked. The mathematical models of the recent Earth's surface vertical motions of the main tectonic blocks on the territory of Ukraine were created as a result of fulfilled investigations.

THE PROGRAM OF THE CARPATHIAN BELT GEODYNAMIC STUDY

E. Zablotskyj (State University "Lviv Polytechnic", Bandera str. 12, 290646 Lviv, Ukraine)
S.Kruglov (Geological Research Institute, Mitskevych sq. 8, 290601, Lviv, Ukraine)

In 1996 a research program for the geodynamic study of the Carpathian Belt has been worked out in Ukraine, which is an integrated part of the program "Geotectonic Analysis of the Region of Central Europe" (CEI-CERGOP, SG8). Monographic descriptions of four adjacent regions with the Carpathian Belt as a key location are in preparation. The main emphasis is made on the tectonic regionalization, establishment of the geotectonic connections of the Carpathians with the other regions of the Central Europe, elucidation of the structural regularities and peculiarities of tectonic covers. The modern concepts about the deep-laid structure of the region are based on the data obtained from the deep and super deep borehols, seismic sounding, studies of gravity and magnetic fields as well as observations of seismisity, heat flows, and other phenomena. The establishment of the Alpine geodynamics is based on the studies of correlation between the sedimentational, magmatic, metamorphic, and geotectonic processes in Permian-Miocene, while neogeodynamics is traced through the high-precision geodetic, deformometric and seismo- acoustic observations, detection of the variations in the geomagnetic field, isostatic state and modern heat flow. It is expected that obtained regional geodynamic regularities could be extrapolated beyond the limits of the Central Europe. The Carpathian Belt together with the Pannonian Depression and the Dinarides should be viewed as a test area for the creation of the modern global geodynamic concept.

THE INFLUENCE OF A SEISMIC EFFECT ON THE RANDOM ERROR OF THE BALLISTIC GRAVITY METER

E.Zanimonsky, A.Kostin („Metrologia"-Kharkiv, Mironositskaja 40 - Ukraine)
A.Pachuta (Warsaw University of Technology, Pl. Politechniki 1, Warsaw, Poland)
L.Siporski (Institute of Geodesy and Cartography, Warsaw, ul. Jasna 2/4, Poland)

External seismic disturbances are a powerful source of random errors of ballistic gravity meters. Traditional means of struggle with them is apparatus filtration. So, the evaluation of the measured values is made by the function of the interference distribution and statistical characteristics of the smoothing process. This paper describes the possibility of using LaCoste and Romberg gravity meter as a seismometer at the evaluation of the seismic conditions at the stations and at the organization of the control process of data accumulation in the ballistic instrument. Continuous registration of the output signal of LCR in computer gives the possibility to generate the signal which interlocks ballistics at the moments of extreme seismics.The experiments found that gravity meter with a feedback system is more suitable for these purposes. By optimization of system parameters one can reduce twice the seismic part of the error at 20% increase of the observation time. The typical parameters of the functions of the interference distribution and readings gravity value differ from Gauss ones. So, the use of the coefficient "square root from number of oservations" for the evaluation of the random error of the result is unacceptable.The direct evaluation of average value variations on many samples is about two times less then that in the case of the Gauss law.

G17 PRARE system: performance and results

Convener: Reigber, C.
Co-Convener: Aksnes, K.

ERS-2 ORBITAL ANALYSIS

P-H. Andersen, Forsvarets Forskningsinstitutt (FFI), Box 25, N-2007 Kjeller, Norway
K Aksnes and H. Skonnord, Institute of Theoretical Astrophysics, Box 1029 Blindern, N-0315 Oslo, Norway

The purpose of this analysis has been to investigate the accuracy with which the orbit of ERS-2 can be computed with the GEOSAT software based on PRARE and SLR tracking data and the EGM96 geopotential. The data cover the period May-June 1996, split up into 5.5 days arcs with up to 10 PRARE stations and 16 SLR stations per arc. The paper describes the analysis strategy and and models employed. Despite certain problems with PRARE biases, the two data types appear to yield comparable accuracies.

SYSTEM PRARE AND FORECASTING OF THE EARTH IONOSPHERE

Andrianov V.A., Smirnov V.M. Revnivyx S.G., Mitrikas V.V. Institute of radioengineering&electronics, Russia
Hartl Ph. Institute of Navigation, Germany

The accuracy of determination of orbit parameters of satellites at observation from the Earth gains the important value. The system PRARE is a dual frequency system, serving for high-precision determination of orbit parameters of satellites. Accessible by it cm and dm accuracy allows to receive the unique information in many areas. One of possible applications of the given system there is the diagnosing of a condition of the Earth ionosphere for forecasting of propagation of radio waves. The methodical aspects of a method of determination of high-altitude distribution of electron concentration of the Earth ionosphere are developed in IRE. The experimental approbation of a method is executed because of observations of dual frequency satellite systems "Glonass" and "Navstar". The first outcomes are obtained on measurements of a PRARE system. The analysis of obtained outcomes allows to hope, that the given system with its high accuracy of determination of time delay and frequent issue of measurements at the appropriate adaptation of the software can become one more tool in problems of forecasting of the Earth ionosphere for various geliophysical conditions.

PRARE SYSTEM PERFORMANCE

S. Bedrich, **F. Flechtner**, Ch. Förste, Ch. Reigber and A. Teubel (GFZ Potsdam, Div.1, D-PAF, c/o DLR, Postfach 1116, D-82230 Oberpfaffenhofen, Germany)

The two-way microwave satellite tracking system PRARE is in routine operations onboard ERS-2 since January 1st, 1996. With the assistance of a global network of mobile, autonomous user ground stations the space segment performs simultaneo us two-way pn-coded range and carrier shifted range rate measurements at sub-dm resp. sub-mm/s level of accuray.
The paper will describe the status of the PRARE control segment consisting of the Master Station in Oberpfaffenhofen, the Monitoring and System Command Statio n in Stuttgart and the Calibration Station in Potsdam as well as the status of the ground tracking network. Beside the PRARE data flow and preprocessing procedures the data quantity, qualitity and distribution will be explained. Finally results
of the PRARE range calibration versus laser ranges at GFZ Potsdam will be presented.

MODELING OF THE IONOSPHERE WITH PRARE

S. Bedrich, **F. Flechtner** and A. Teubel (GFZ Potsdam, Div.1, D-PAF, c/o DLR, Postfach 1116, D-82230 Oberpfaffenhofen, Germany)

The two-way microwave satellite tracking system PRARE is in routine operations onboard ERS-2 since January 1st, 1996. Beside very precise 2-way range and range rate measurements between the space segment and a global distributed network of tracking stations used for orbit determination and point positioning two different methods are used to derive the corresponding ionospheric corrections as well as the total electron content (TEC) in slant and vertical direction:
a.) The one-way code travel time difference between the simultaneous transmitted X- and S-band signal is measured in the ground stations continuously during every pass.
b.) The effect that the continuous available 1 per second two-way range and rang e rate measurements propagate with different velocities (group resp. phase vel ocity) can be used to calculate the ionospheric correction using the DRVID (differe nced range versus integrated doppler) principle.
The paper describes both methods as well as first results to calibrate and valid ate the ionospheric data. Relative calibration has been performed using data of adja cent installed stations against which the absolute calibration has been derived from stations operated in common view mode. Finally the PRARE derived TEC data are compared wi th ionospheric models like Bent, IRI90, IRI95 or PIM. Further plans to calibrate an d validate the data will be discussed.

A NEW METHOD FOR HIGHLY PRECISE TWO-WAY COMMON-VIEW TIME TRANSFER BETWEEN GROUND-BASED ATOMIC CLOCKS WITH PRARE

S. Bedrich (GFZ Potsdam, Div.1, D-PAF, c/o DLR, Postfach 1116, D-82230 Oberpfaffenhofen, Germany)

The Precise Range And Range-Rate Equipment PRARE is in nominal operations onboard the European remote sensing satellite ERS-2 since May 1st, 1995. As the system is basically designed for highly precise satellite tracking and point positioning, the measurement principle is based on the high- frequency pn-code correlation method with synchronous carrier phase comparison. An important option is the tracking of up to 4 ground stations simultaneously.
In a dedicated experiment in December 1995, these features have been taken advantage of to intercompare by a two-way common-view approach 3 ground based time normals with PRARE: a Rb-clock at GFZ Oberpfaffenhofen, a H-Maser clock at DLR Weilheim, and a Cs-clock at GFZ Potsdam.
In a thorough correlation process, which took into account all necessary individual signal corrections as well as atmospheric, hardware, and methodically induced signal delays, the ground clocks' relative time offset could be determined with a precision of down to 400 ps. These results were repeatedly confirmed and could be verified by simultaneous GPS common-view time transfer, as the clocks were partly connected to GPS time receivers during the experiment. The paper reviews the experimental setup and proves that the PRARE system is fully applicable for easily achievable, highly precise common-view time transfer between remote atomic clocks.

OPERATIONAL EXPERIENCE WITH BANGALORE, PRARE STATION

K.Elango (ISTRAC/Indian Space Research Organisation, Department of Space, Bangalore-560 058, India)
F.Flechtner (GFZ Potsdam, Div. 1, D-PAF, C/o.DLR, Postfach-1116, D-82230, Oberpfaffenhofen, Germany)

The Precision Range and Range Rate Equipment (PRARE) from GFZ, Potsdam, Germany was installed at ISTRAC Campus, Bangalore, initially for ERS-1 support.Subsequently, it was commissioned to support Russian Spacecraft carrying PRARE, METEOR-3/7 and has switched over to support ERS-2 and continuing till date. Though minor problems were faced during this period, the Bangalore PRARE is giving good support and providing valid data to the central data base. This paper presents an overview of the operational experience gained over the last two years. Total percentage of station availability has been provided. The reasons for outage are analysed to provide feedback for further improving the availability of the system. The statistics of PRARE support and the observations on HRD data have also been provided in this paper.

POSITIONING OF A MOVING PRARE STATION IN ANTARTICA

O. Heinze and H.W. Schenke (Alfred-Wegener-Institut, Institute for Polar and Marine Research, Postfach 12 01 61, D-27515 Bremerhaven, Germany)
J.-C. Raimondo and F.-H. Massmann (GeoForschungsZentrum Potsdam, Div.1, D-PAF, c/o DLR, Postfach 1116, D-82230 Oberpfaffenhofen, Germany)

The PRARE ground station of the Alfred-Wegener-Institut (AWI) was installed at the German wintering station "Neumayer" in Antarctica (70.66 S, 8.25 W) in January 1996. The PRARE station is very successfully operating since February 1st, 1996 with an average of 12 passes/day.
Since the "Neumayer"-Station is established on a floating ice-shelf a remarkable horizontal station movement of about 40cm/d occurs. This station movement requires another post-processing strategy and interpretation than for the other PRARE stations.
Also GPS measurements were performed at "Neumayer" with a permanently installed ASHTECH Z-12, dual frequency, Y-code, 12 channels GPS-receiver. The GPS data reduction and the combination with IGS stations was done with the GAMIT/GLOBK program system from the MIT.
Both, coordinate and movement solutions from the PRARE and GPS stations at the "Neumayer" Station will be compared and discussed.

POINT POSITIONNING AND EARTH PARAMETERS DERIVED FROM ERS-2 PRARE DATA

J.-C. Raimondo, A. Bode, K. Enninghorst, F.-H. Massmann and K.-H. Neumayer (GFZ Potsdam, Div.1, D-PAF, c/o DLR, Postfach 1116, D-82230 Oberpfaffenhofen, Germany)

The German Microwave Tracking System PRARE due to its geographical coverage and weather independency is a good tool for Precise Orbit Determination (POD) and many other applications. In this presentation some of th ese applications namely Point Positionning and Earth Orientation Parameters (EOP) determination using PRARE data are evaluated. PRARE has the advantage of providing two simultaneous measurement types (Range and Doppler) allowing comparisons for the earth parameters and station coordinates determination. The presentation will focus on the result s that can be obtained using the different measurement types taken separately or in a combined fashion. Moreover the inclusion of the PRARE data to improve the g ravity field model will be discussed.

ERS-2 PRECISE ORBIT DETERMINATION WITH PRARE

K. Enninghorst, F.-H. Massmann, K.-H. Neumayer and J.-C. Raimondo (GFZ Potsdam, Div.1, D-PAF, c/o DLR, Postfach 1116, D-82230 Oberpfaffenhofen, Germany)

The use of PRARE (Precise Range and Range Rate Equipment) data has improved and simplified the operational determination of preliminary and precise orbits of ERS-2. After the discussion of the amount of data and its geographical distribution compared with satellite laser tracking and tracking data based on altimeter crossover height differences, the used models including the PRARE specific solve-for parameters are presented. In addition, the quality and the small deviations (less than 3 cm radially) of orbits based on different types of tracking data are discussed in detail.

CALIBRATION OF PRARE IONOSPHERIC DATA BY GPS DERIVED TEC DATA

N. Jakowski and E. Sardon (DLR e.V., Fernerkundungsstation Neustrelitz, Kalkhorstweg 53, 17235 Neustrelitz)

The microwave satellite tracking system PRARE onboard ERS2 provides the opportunity to measure the latitudinal profile of the Total Electron Content (TEC) of the ionosphere near the globally distributed PRARE ground stations. TEC can be obtained by measuring the time delay of coded signals at S- and X-band frequencies. However, since these measurements are biased due to hardware delays, the measured data have to be calibrated by reliable methods. The method we discuss in this paper compares PRARE data with corresponding GPS derived vertical TEC maps. After converting the vertical TEC data taken from the TEC map along the ionospheric trace of the ERS 2 satellite to the momentan PRARE raypath and assuming a constant plasmaspheric electron content of about $2x10^{16}$ el/m^2, the TEC or time delay bias is estimated for different European PRARE groundstations.
As preliminary results indicate, PRARE measurements can provide valuable contributions for monitoring and studying the latitudinal dependence of ionospheric processes.

PRECISION ORBIT DETERMINATION FOR ERS-2

J.C. Ries (Center for Space Research, University of Texas, Austin, Texas, 78712, USA)
J.B. Bordi, C.K. Shum, and B.D. Tapley, (Center for Space Research, University of Texas, Austin, Texas, 78712, USA)

The ERS radar altimeters have demonstrated the ability to measure the sea surface height with a precision of a few cm with unprecedented latitude coverage. The ability to compute orbits at a comparable level are an inherent requirement to fully exploit the scientific usage of the radar altimeters. Hence, a good temporal and geographic distribution of precise tracking data is essential to determine the various parameters which must estimated as part of the orbit determination procedure. We present an analysis of orbits computed for ERS-2 using various techniques and models. This includes employing dual altimeter crossover measurements between ERS-2 and TOPEX/POSEIDON together with laser tracking, combinations of PRARE range and range-rate tracking, as well as the use of improved gravity field and ocean tide models. Independently determined orbits will be compared to provide an analysis of the satellite height differences, and a comparison of sea surface topography solutions with those obtained from TOPEX/POSEIDON will be presented to provide an accuracy assessment. Results of our assessment of the PRARE tracking data is also presented.

INCORPORATION OF PRARE DATA IN ERS-2 ORBIT COMPUTATION

Pieter Visser, Remko Scharroo and Boudewijn Ambrosius (Delft Institute for Earth Oriented Space Research, Delft University of Technology, The Netherlands)

A capability has been successfully implemented to include tracking data acquired by the German Precise Range and Range-rate Equipment (PRARE) in the ERS-2 precise orbit computation in combination with Satellite Laser Range (SLR) measurements. By combining these two data types, deficiences in the SLR tracking network, such as a concentration of laser stations in the Northern Hemisphere, can be overcome, and orbits can be computed with a radial accuracy competitive with orbits based on SLR and altimeter crossover measurements. Being able to compute high-precision orbits independent from altimeter measurements is a a situation much preferred by the scientific community, preventing aliasing of oceanographic signals in the orbit.
A rich data set of ERS-2 PRARE measurements has become available since January 1, 1996. This data set has been evaluated extensively for use in ERS-2 orbit determination, estimation of PRARE station coordinates, and gravity field model tailoring experiments. Altimeter crossover analyses indicate that combined SLR/PRARE orbits are more accurate than SLR-only orbits, about 3 cm rms-wise in the radial direction, and reach the accuracy level of SLR/crossover orbits. Using a tailored gravity field model based upon these data leads to even higher radial orbit accuracies, with altimeter crossover residual rms values below 9 cm for 5.5-day data arcs.

NATURAL HAZARDS (NH)

NH1 Prediction and management of extreme events

Convener: Tinti, S.
Co-Convener: Massinon, B.

MOVING BOUNDARY SIMULATION IN LONG WAVE NUMERICAL MODELING

A. Balzano (Land Engineering Dept., Hydraulics Section, Cagliari, Italy)

Simulation of moving boundaries is an essential feature of numerical models of tidal currents, storm surges or river flooding. Seven existing methods for use in finite difference implicit two-dimensional shallow water flow models are first discussed and compared. These can be applied also to three-dimensional barotropic models based on natural coordinates, in that the latter effectively reduce to two-dimensional for small depths. Two main drawbacks of these methods are pointed out, as to the effective retention volume estimation and the computation of the current depth between two adjacent cells of the computational grid. In particular, the latter deficiency causes a clear unphysical effect for subcritical bed friction controlled flows. This is shown by means of simple but effective 1D tests. Two new methods for water depth estimation and one new relation water level-retention volume for dry cell declaration are then proved to overcome the above inadequacies. Finally, all the methods discussed are verified with a 2D test case of free oscillations on frictionless paraboloidic bottom, for which the analytical solution is known. All the methods are defined as global and local mass conserving. The three new methods turn out to be the most accurate. However, the (nonlinear) new method for dry cell declaration is quite time consuming because of the iterations required. Thus it appears to be unpractical for long-term simulations often needed in environmental problems but suitable for real-time storm surge predictions. For long-term simulations one of the two new methods for water depth computation is to be preferred.

THE ASSESSMENT OF TECTONIC FAULTS FOR THE CONSTRUCTION IN ACTIVE TECTONIC REGIONS

Olga S. Barykina, Moscow Lomonosov State University, Moscow, Russia.

The study of tectonic faults is essential for the proper planning and construction of engineering structures in active tectonic areas. The author suggests to regard the fault zone as a special geologic massif, which is characterized by the stretched form, zonal structure, unfavourable engineering geologic conditions, and it complicates the fault estimation.
The paper presents the fault classification based on the analysis and generalization of materials on the fault tectonics received during investigations in the regions of different geologic formations. This paper considers the mother rock composition as one of the main factors influence on the fault structure, composition, properties, sizes and others. Three categories of rocks according to the way they reveal the fault zones are divided. Metamorphic rocks and rocks of magmatic intrusions are united in the first category. Sedimentary carbonate rocks and highly stability sand-stones reffered to the second category. Low stability sand-stones, argillities and aleurolites form the third category. This classification takes into consideration the morpho-genetic peculiarities of the fault, its mechanism and the time of its formation, the parameters of the fault zone, the composition and condition of disjunctive massif, the present mobility of the fault and the peculiarities of the interaction between the faults and engineering structures as well.
The fault typization allows to predict currently unknown regularities, to work out the rational methods of the study of faults in active tectonic areas.

THE EXPERIENCE AND SOFTWARE OF MARINE NATURAL HAZARDS ESTIMATION

A.V. Boukhanovsky and A.B. Degtyarev (Institute High Performance Computing and Data Bases, 194291 St.Petersburg P/O box 71, Russia)
L.J. Lopatoukhin and V.A. Rozhkov (State Oceanographic Institute St.Petersburg Branch, 199026 St.Petersburg, 23 line, 2A, Russia)

One of the main marine hazards, affecting the human activity in the coastal zone, are the wind, waves, level variations, and storm surges in any seas. The input to software either the measured marine parameters or simulated by hydrodynamic and stochastic models. Different approaches are used for calculations. By mean of analytical solutions, stochastic simulations and experimental investigations it is shown the dependence of extreme wave heights from the used method.
The analytical and numerical results of investigations of sensitivity to threshold selection is demonstrated. For selected cases distributions of extreme values are calculated. The objective of extreme value analysis is to estimate rare return period (5, 10, 50 or 100 year) waves. The ensemble of asymptotic distribution is used, namely, Gumbel and Weibull. Various goodness-of-fit tests are used. Different methods of parameters estimation also tested. After adopting the distribution and of the method of parameters estimation the n-year events are calculated. The tolerant and confidence intervals, based on the boot-strap method and Monte-Carlo simulation, is calculated. So, the extremes and it reliability are investigated. The examples of calculations for some Russian seas will be presented.

THE RESULTS OF A TWO YEARS MONITORING OF A SHALLOW UNDERGROUND WATER LEVEL NETWORK IN THESSALY, CENTRAL GREECE,FOR SEISMIC PRECURSORY PHENOMENA

M.E. Contadakis, D.Arabelos, G. Asteriadis, (Department of Geodesy and Surveying, University of Thessaloniki 54006 , Greece .)

It is known that tectonic stresses resulting to seismic activity result also to temporal or permanent changes of the tectonic environment of an aquifer, which in turn can be detected on the water level of a borehole or well facing the aquifer. In July of 1994 the Department of Geodesy and Surveying, University of Thessaloniki, started the follow up of the the changes in the level of the shallow underground water at a well network in South Thessaly, with respect to the seismic activity in the area . As it has been already reported in earlier paper, statistical tests show that the daily measurements samples of the water level variations of the network are weakly influenced by the barometric pressure and gravity tidal variations (with a phase lag of about a month at the two of the stations),while the hourly measurement samples of the underground water level are not influenced by the earthtides. No major seismic event occured during the two year in the area covered by the network. Nevertheless an effort to identify variations of the underground water level caused by the local microseismic activity, after the reduction of the observations from the effect of the non tectonic stresses and the precipitation has been performed, succeeded to a level of 50% .The percentage of the successful identifications is dramatically increased if we consider only shocks with magnitude greater of 3.0. These results are in favor of using this cheap method in an interdisciplinary network for earthquake precursory phenomena detection.

LOWER IONOSPHERE MODIFICATION AS A RESULT OF THE CHERNOBYL NPS ACCIDENT

I.M.Fuks, O.A.Litvinenko, R.S.Shubova (4 Chervonopraporna St., Institute of Radio Astronomy, National Academy of Sciences of Ukraine, Kharkiv, 310002, Ukraine)

The radio signals with the carrier frequency f=16 kHz of the precise time and frequency service transmitter GBR (Rugby, Great Britain) have been received in Kharkiv for many years - since 60th. The propagation route (~ 2600 km long) passes through the very vicinity of the Chernobyl NPS. Anomalous amplitude and phase signal variations appeared on this route during the accident at the 4-th block of NPS. R.m.s. amplitude fluctuations increased in 2.1 times and phase - in 3.8 times. These variations had a quasi periodical character with a period ~1.5-2 hours and were observed since April 25 till May 10, 1986 - the date of the damaged block final covering. Comparison of the anomalous signal variations with the physical process series at the NPS and the radioactive nuclide pollution data led to the conclusion that the VLF communication channel (Earth-ionosphere wave guide) perturbations were caused by the noble gas and light volatile element (Xe, Kr, J, Te, etc.) discharging. Calculations based on the experimental data showed that the signal variation increase may be caused by the appearance in the lower ionosphere of the inhomogeneity with linear length =300 km and the D-layer lower boundary drop by 5-10km. The quasi periodical signal variations are similar to the ones appearing in the VLF as earthquakes precursors, but their physical cause has not yet been clarified. It may be supposed that in both cases there is the common cause of such variations - the signal modulation by the eigen Earth oscillation (the so-called, seismo-gravitational pulsations).

NUMERICAL SIMULATION OF A POTENTIAL LANDSLIDE-GENERATED TSUNAMI IN THE CARIBBEAN SEA

Ph. Heinrich (Laboratoire de Détection et de Géophysique, Commissariat à l'Energie Atomique, B.P.12, 91680 Bruyères-le-Châtel, France)
S. Guibourg, R. Roche (Laboratoire de Détection et de Géophysique)

The volcano of Montserrat (Antilles, Caribbean Sea) is erupting. The explosion of this volcano could lead to the collapse of a portion of the lava dome and to a sudden entry of debris flows into the Caribbean Sea. In the worst case scenario, the volume of material reaching the sea has been estimated at 80 millions of cubic metres. The sliding of this mass and the generated water surface have been simulated numerically, assuming that the debris behave like a viscous fluid flowing into the sea. The numerical model solves the 3D Navier-Stokes equations for a mixture composed of sediments and water. The generated water waves is then propagated around the coast of Montserrat and in the direction of Guadeloupe by means of shallow water models. The numerical results show that wave heights could be as high as 10 m in the generation area. Waves reach Guadeloupe after about 10 minutes with amplitudes ranging from 1 to 2 metres.

ANALYSIS OF TSUNAMI HAZARD IN THE BLACK SEA

S. F. Dotsenko (Marine Hydrophysical Institute Academy of the Ukraine National Academy of Sciences, 2, Kapitanskaya st., Sevastopol, 335000, Crimea, Ukraine)

The list of tsunamis in the Black Sea during the last 20 ages includes below 20 events. At least four antique tsunamis were distractive with heights up to 3-4 m. The tsunamis in 1927,1939 and 1966 were recorded by water-level gauges along coastline of the Caucasus and Crimea. Their heights did not exceed 0.52 m. It is impossible to exclude large tsunami generation here in a future.

Ray and long-wave numerical models were developed to study tsunami in the Black Sea. A strong wave trapping by shelf was found for main seismic zones of wave generation. So tsunami excited near the east coast of the Sea are not hazardous for the west coast. The height of wave over shelf is 2-3 times the initial value. Tsunami run-up on a vertical wall at 10 m depth is 6-8 times as much as amplitude incident nonlinear wave. Tsunami travel time across the Sea along latitude or longitude is 30 min or 110 min respectively. It is very difficult to provide defense of population of the Black Sea region during feasible tsunami.

LANDSLIDE SIMULATION BY CELLULAR AUTOMATA

S. Di Gregorio, R. Rongo, W. Spataro (Department of Mathematics, University of Calabria, I 87036 Arcavacata di Rende, Italy)
C. Siciliano (Sodalia, via del Brennero,364, I 38100 Trento, Italy)
M. Sorriso (CNR IRPI, via Verdi 248, I 87030 Roges di Rende, Italy)

Cellular Automata (CA), a paradigm of parallel computing, represent an alternative to differential equations and are used for modelling and simulating very complex phenomena; CA models have been developed by our research group for the simulation of landslides. We present SCIDDICA-3, our most efficient model, a two-dimensional CA model together with the simulation results of the mount Ontake (Japan) debris avalanche which occurred in 1984. Landslides are viewed as a dynamic system based exclusively on local interactions with discrete time and space, where space is represented by square cells, whose specifications (states) describe physical and chemical characteristics (friction, viscosity, altitude, debris thickness, etc.) of the corresponding portion of space. At the time t=0, cells are in states, which describe initial conditions; the CA evolves then changing the state of all cells simultaneously at discrete times. Input for each cell is given by the states in the adjacent cells; the outflow computation from the cells gives the evolution of the phenomenon. The comparison between the real and simulated event is satisfying within limits to forecast the surface covered by debris.

PREDICTION AND MANAGEMENT OF EXTREME EVENTS BASED ON A SIMPLE PROBABILISTIC MODEL OF THE TIME-PASSAGE BOUNDARY.

Ivanov L. M., T. M. Margolina and O. V. Melnichenko (Marine Hydrophysical Institute Ukrainian National Academy of Sciences, 2, Kapitanskaya St., Sevastopol 335000, Ukraine)

If an evolution of extreme event can be described by a Markovian diffusion approximation and that the evolution equations can be reduced to a system of ordinary differential equations, a method for prediction and management of natural disasters is developed. In this approach the three quantitative characteristics of a disaster, such as, the probability of realization, the mean time before the realization and the dispersion of the mean time are calculated. In addition the problem of synthesis of stochastic optimal control of disaster risk based on nonliear probabilistic criteria has an unique solution and an accurate management can be reached. An application to the problem of radioactive damping in the Kara Sea illustrates the theory.

THE INDUCED EARTHQUAKES AND RETARDED TSUNAMI WAVES

V.V.Ivanov Institute of Marine Geology & Geophysics. Yuzhno-Sakhalinsk, Nauka street. Russia.

The seismic records and tsunami wave records of the Earthquakes 3.9.1992 (Nicaragua), 12.12.1992 (Flores), 15.1.1993 (Hokkaido), 12.7.1993 (Okushiri) , 8.8 1993 (Guam), 4.10.1994 (Shikotan) are investigated. The High frequency pulse of tsunami retarded on time 2 h 40 min. are discovered on regarded earthquakes. The low frequency seismic signal retarded on time 2h. 40 min are discovered on the records of the stations near to the source. We regards these events as events caused by the same process. By analyzing the records of the stations located on far distances there are discovered that this low frequency signal is the Raleigh waves of the Earthquake, which come to the source after propagating around the world with velocity 4 km/s. This wave come to the earthquakes area and stimulate increasing of the seismic activity . This activity accords the pulse of the high frequency tsunami wave.

REAL TIME MONITORING OF THREE-DIMENSIONAL VOLCANIC DEFORMATION

R. Jackson (Papua New Guinea University of Technology, PMB, Lae, Papua New Guinea)
C. McKee and S. Saunders (Rabaul Volcano Observatory, Rabaul, Papua New Guinea)

The town of Rabaul in Papua New Guinea lies within a volcanic caldera whose latest major eruption was about 1400 years ago. Historical eruptions were relatively small and took place from vents near a suspected ring fault system within the caldera. In the latest eruptions (1994-96) parts of Rabaul Town and neighbouring villages were destroyed. From the start of these eruptions the EDM trilateration and the spirit levelling networks could not be re-occupied because of losses of large parts of the networks. There was little information on ground deformation as the eruptions progressed and it could not be determined whether those eruptions would remain small or evolve to larger, perhaps caldera forming events. A permanent real-time GPS array is now being introduced at Rabaul to help resolve questions about eruption scale. The system will allow monitoring of the position of three receivers placed at significant deformation points in the caldera, from the Rabaul Volcano Observatory situated on the northern rim of the caldera. This permanent array should give continuous ground deformation information even in conditions which threaten potential major eruption. Initial data will be presented indicating the precision with which this information can be obtained by the system over the 10km baselines. Quality control issues with reference to accuracy will be addressed.

NUMERICAL SIMULATION OF THE LANDSLIDE GENERATED TSUNAMI, 3 NOVEMBER, 1994, SKAGWAY, ALASKA

E.A. Kulikov, A.B. Rabinovich (P.P. Shirshov Institute of Oceanology, Russia)
I.V. Fine (Institute of Heat and Mass Transfer, Minsk, Belarus)
R.E. Tomson (Institute of Ocean Sciences, Sidney, BC, Canada)
B.D. Bornhold (Pacific Geoscience Centre, Sidney, BC, Canada)

The modified numerical model of Jiang and LeBlond (1994) was used to simulate a landslide generated tsunami. This 3-dimensional model was generalized to include actual bottom topography and subaerial slide case. The slide is treated as an incompressible, isotropic viscous fluid and the seawater as an incompressible inviscid fluid. The long-wave approximation is used for both the surface waves and the slide. The submarine slide is characterized by laminar, quasi-steady viscous flow.

The present model was used to simulate catastrophic landslide tsunami event of 3 November, 1994, Skagway. The tsunami waves, estimated by eyewitnesses to have heights of 5-6 m in the harbor and 9-11 m at the shoreline, were recorded by a NOAA analog tide gauge located on the west side of the harbor. The numerical simulation of the corresponding sea level changes gave results that closely agreed with the tide gauge records and the eyewitness observations.

The present study was partly supported by Russian Foundation of Basic Research project #96-05-65145.

THE FLOOD OF NOVEMBER 5-6, 1994 IN PIEMONTE REGION (NORTHWEST ITALY): CAUSES AND RELATIVE EFFECTS IN THE TANARO VALLEY

Fabio Luino - Italian National Research Council, Strada delle Cacce 73, I - 10135 TORINO - ITALY

During the first week of November 1994, a wide and persistent depression over Northwest of Europe provoked heavy rains over a large part of Piemonte region. Many raingauges recorded precipitation about 200 mm/day. In 92 weather stations, with records spanning a period of 60-80 years, precipitation exceeded the previous annual maxima, in 18 cases for 1 day and 20 cases for 2 days in succession. Precipitation reached a maximum hourly intensity of 54 mm, with cumulative maximum values of 455.6 mm in 24 hours and 602.6 mm in 48 hours. Exceptional discharges were produced along the principal rivers and also numerous landslides. The discharges were characterized by peaks never previously recorded (discharge per unit area 1.2-7.3 m=FC/s km=FD). Along the main rivers there were large floods with consequent damage to 140 urbanized areas. The effects were catastrophical: 69 victims, 2,200 homeless, and 15 billion $ of damage to private and public property, over all. If we consider the event as a whole, we must go back to May 26-27, 1879 to find a comparable case; in consequence we may regard an event on this scale as occurring once in a century. In this paper the causes and effects that occurred in the Tanaro River basin (area 8,500 km=FD) are analyzed.

CAN TSUNAMI HYDRODYNAMIC MODELLING BE USED AS A TOOL TO NATURAL RISK ASSESSMENT?

L. A. Mendes- Victor, J.M.Miranda, P.M.A.Miranda (Centro de Geofisica, Univ.of Lisbon, R. Escola Politécnica 58, 1250 Lisboa, Portugal, fax +351 1 3953327)
M.A.Baptista (Dept. Engenharia Civil - ISEL, Lisbon)

The evaluation of seismic risk in Europe is dependent on the study of historical catastrophic earthquakes. However, the location, magnitude and source geometry are usually poorly constrained from macroseismic analysis.
When these earthquakes are tsunamigenic, tsunami data constitute an additional source of information to further constrain the seismic study.
In recent years, a great effort is being made to quantitatively model the historical tsunami waves. To do so, both the source location and geometry must be known or, otherwise, historical tsunami data can be used to infer these parameters.
The 1755 Lisbon earthquake is a paradigmatic example. Historical data is considered reliable enough to allow for a good source determination. However the results obtained are different from previous macroseismic studies, leading to a new geodynamic interpretation of the event.
Can a model based on hydrodynamic modelling of historical data be considered reliable enough to change our view on the seismic risk in SW Iberia?

PREDICTION AND HAZARD ASSESSMENT OF INTERACTION BETWEEN GEOLOGICAL ENVIRONMENT AND NUCLEAR ENERGETICS OBJECTS

V.N. Morozov
Geophysical Center, Russian Academy of Sciences
Molodezhnaya 3, Moscow, 117296 Russia

The high requirements to the geodynamic stability in geological environment at thesites of nuclear energetics objects (atomic stations, repositories and burials of radioactive wastes, etc.) and toxic wastes disposals raise a number of new problems in the assessment and prediction of the state of rock massifs. The available geological and geophysical data bases, combined with the monitoring of the environment including the GPS technologies of studying the slow crustal deformations, provide grounds for drawing up scenarios of the possible hazards and their prevention. The methodical procedure basis for estimation of the risk is also the result of research at nuclear energetics objects.

INTEGRATION OF UNCERTAINTY IN A DETERMINISTIC APPROACH FOR SEISMIC HAZARD ASSESSMENT

I.M. Orozova (Dip. Scienze della Terra, Univ. Trieste, v.E.Weiss 1-4, 34127 Trieste, Italy)
P. Suhadolc (Dip. Scienze della Terra, Univ. Trieste, v.E. Weiss, 1-4, 34127 Trieste, Italy)

One of the negative sides of the deterministic approaches for Seismic Hazard Analysis (SHA) is that they do not give any idea about the uncertainties in the input and output parameters. In the present study we propose a method to include some uncertainties in the deterministic approach for SHA, developed by Costa et al. (1993). This deterministic approach among the other parameters makes use of a controlling earthquake (fixed magnitude, usually the maximum observed) to estimate the ground motion at given site. The final result is presented as the maximum ground motion parameter at each receiver. In the present study we propose the use of number of earthquakes of different magnitudes, to each of which is assigned an uncertainty (i.e. annual probability of exceedance). This uncertainty together with other considerations is then used to assign a probability of exceedance to the estimated ground motion parameter (GMP) at each receiver. The final result can be presented as a map contouring the sites with GMP having equal probability of exceedance in given exposure time and can be easily compared with the results of probabilistic hazard estimations. This method allows a more robust analysis of the seismic hazard. It has been applied to some areas in Italy.

LESSONS FROM TSUNAMI POST-DISASTER FIELD SURVEYS

Efim Pelinovsky, (Institute of Applied Physics, 46 Uljanov Str., Nizhny Novgorod, 603600 Russia; email:enpeli@appl.sci-nnov.ru)

Results of post-disaster field surveys after the Shikotan Earthquake (04.10.94) and the Sulawesi Earthquake (01.01.96) are presented. Both earthquakes occurred in the immediate vicinity from the coast and induced tsunami waves. Obtained data of tsunami characteristics are used to estimate the tsunami-risk for these regions and the validity of modern physical and mathematical models of the tsunami phenomenon. An important problem of the land subsidence during a tsunamigenetic earthquake is discussed. Visual low-accurate estimates of such subsidences are usually used in tsunami survey practice. As a result, high accuracy of wave height measurements with account of tides is impaired by low accuracy of land subsidence measurements. This issue requires special consideration, since appropriate measurement need different equipment and large financial investments. The results of a special survey of measuring of the subsidence during the Shikotan tsunami 04.10.94 are shown (the island subsided by approximately 50 cm). Comparison of the cumulative distribution of tsunami runup heights for both events is given. Problems of the prediction and mitigation of both tsunamis are discussed.

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Prognosis peculiarities of the Caspian Sea level variations in the systems Sun-Earth.

D.Sadykov, Abay University,O.S.Turkov-SC "Kazakhstancaspshelf", D.R.Seyfullin-National Technical Universiti, Almaty, Republic of Kazakstan.

Though the influence of many natural processes (geodynamic, geliophysical, atmospherical, hydrological etc. onto the Caspian Sea level dynamics is accepted by many scientists, but the cyclicity mechanism of this event is not known.Main reason of this ambiguity is related to the nonlinear connections between the mutual action of the forces due to the masses, energy impulse, electromagnetic and nuclear interaction of the bodies and their consequences of the processes in atmosphere,hydrosphere, lithosphere within Sea area. Such nonlinear connections defined by the quasistationary and im- pulse forces does not permit to use effectively the known statistical and spectral methods of analysis.So, prognosis of the Caspian Sea level variations needs consideration of the nonlinear decrease of the water volume during the prolonged geological time period and the change of the volumetric deformation and its transition to the surface one, also the mutual influence of the surface and underground hydrosphere.The same technique can be used when accounting the influence of the circulation type and Earth pole drift onto the sea dynamics due to the impulse Sun energy and the other space factors fluctuations,also Earth contraction trend by the longitudinal and latidudinal deformations of the alternating signs.Such prognostion method made it possible to define the cyclicity of the "high" and "low" water level and the length of periods as units of sun activity by 11,22 and 90 years.New element of this method is represented by the absence of the distinct uniform periodicity of sea level fluctuation whereas the process itself is uniform during transgression and regression stages. Analysis of such dynamic processes as the fluctuations of sea level under influence of the united action of many factors requires the most effective method, which use characteristics of fracthionation, deterministic chaos and topological dynamic,which does not disturbe the natural totality of the different components varying by their time perspectives and amplitude features in the observed series.

METHODS of CALCULATION of TSUNAMI RISK

Efim Pelinovsky, (Institute of Applied Physics, 46 Uljanov Str., Nizhny Novgorod, 603600 Russia; email:enpeli@appl.sci-nnov.ru)

The problem of estimates of the tsunami risk is very complex, and should include human, economic, ecological, and social as well as technical factors. This problem is reviewed here from the viewpoint of runup characteristics. As for any rare event we can apply the methods of extreme statistics. Although the actual frequency distribution of tsunamis is not known, it appears to follow a Poisson distribution. The main characteristic of this distribution is exceedance (cumulative) frequency of events. Three main approaches to calculate the exceedance frequency are used. When there are sufficient data of historical tsunamis, a statistical approach can be used, and a regression analysis determines the function the cumulative frequency of the tsunami runup height. If the number of historical tsunamis is small in each settlement, but enough for a geographic region, it is necessary to use a combination of statistical and deterministic approaches. If there is no practical information about historical tsunamis, only very rough estimates of tsunami risk can be made. Several examples of calculation of the cummulative frequency of tsunami are presented.

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FINITE-ELEMENT SIMULATIONS OF THE 28 DECEMBER 1908 MESSINA STRAITS (SOUTHERN ITALY) TSUNAMI

A.Piatanesi, S. Tinti and E. Bortolucci (Dip. di Fisica, Sett. di Geofisica, V.le Berti Pichat 8, 40127 Bologna, Italy)

The earthquake we are dealing with occurred on December 28, 1908: because of the number of victims (about 60,000) and the extension of the destroyed area (6,000 Km^2), this earthquake, with the epicentral MCS intensity XI, may be considered the strongest event reported for Italian history along with the 1693 eastern Sicily earthquake. The shock produced a large tsunami that caused severe damage and many victims. In all places the first sea movement was a withdrawal for a few minutes, followed by a flooding of the coast with at least three big waves. A post-event survey allowed to estimate damage, flooding and run-up heights (more than 10 m in some places). In this work we perform some numerical simulations of the tsunami generation and propagation, taking into account different source faults: the model is based on the shallow water equations, solved numerically by means of a finite-element method. The computational domain, covered by a mesh consisting of triangular elements, includes the Messina Straits and the sea facing the northeastern coast of Sicily and southern Calabria.

LARGE TSUNAMIS AND TSUNAMI HAZARD FROM THE NEW ITALIAN TSUNAMI CATALOG

S. Tinti (Dipartimento di Fisica, Settore di Geofisica, Università di Bologna, Bologna, Italy) and A. Maramai (Istituto Nazionale di Geofisica, Rome, Italy)

A new catalog of the Italian tsunamis has been recently published following criteria established in the frame of the EU GITEC project for a unified catalog of the European tsunamis. The catalog differs remarkably from the previous compilations of the Italian tsunamis due to Caputo and Faita (1984) and to Bedosti and Caputo (1986), the main difference concerning the number of events: the present version includes only 67 events of which 30 are certain (reliability class 4), whereas the rest are affected by various degree of uncertainty (reliabiltiy from 0 to 3 in the Iida's scale). Only two catastrophic events are well documented (the 6 Feb 1783 Calabria tsunami and the 1908 Messina Straits tsunami), but several more resulted to be disastrous or relevant events. Large events are reexamined and the catalog is analysed in view of determining the hazard from tsunamis along the Italian coastlines and the implication for suitable mitigation strategies. The regions with the highest number of observed tsunamis happens to be the Aeolian Islands and the Liguria-Côte d'Azur, while the events associated with the largest waves were observed in the Messina Straits, the Tyrrhenian Calabria and the Gargano promontory.

THE MIAGE GLACIER IN THE VALLEY OF AOSTA (WESTERN ALPS, ITALY) AND THE EXTRAORDINARY DETACHMENT OCCURRED ON AUGUST, 9 1996.

Tinti S. (Dip.to di Fisica, Settore di Geofisica, Università di Bologna, Italy)
A. Maramai (Istituto Nazionale di Geofisica, Rome, Italy)
Cerutti A.V. (Via Promis, 1, Aosta - Italy)

The Miage glacier, the biggest in the Italian side of the Mont Blanc, is located few Km west of Courmayeur, at about 2.050 m above the sea level. An alpine lake, called Miage Lake, is present at the glacier and the high dynamics of the glacier, with falls of pieces of ice into the lake, represents an important tourist draw. On August 9, 1996, after a long period of heavy rain, a big sheet of ice, approximately 40 m width by 10 m height, fell into the lake provoking an anomalous wave that involved many tourists, causing some seriously wounded people. This work aims at better understanding the dynamics of the glacier in the Valley of Aosta (avalanches, snowslides, etc.) and to evaluate the risk in the area. An attempt to model the August 9, 1996 detachment in the glacier is also in progress.

ON A TENTATIVE EXPLANATION OF THE SELECTIVITY EFFECT

P. Varotsos, N. Sarlis and M. Lazaridou. (Solid Earth Physics Institute, University of Athens, Greece)

Concerning the transmission of Seismic Electric Signals (SES) at large epicentral distances, previous publications by other groups claim that, in order to detect signals at epicentral distances r~100km, unreasonably huge current.intensities (~10^4A) have to be emitted from the focal area.
By considering a plausible conductive path, from the focal area to the vicinity of the measuring site (as suggested by the model published of Varotsos et al. *Tectonophysics 224*, 1-37, 1993), we present a theoretical calculation, which explains that, even a current intensity of 1A, is sufficient to produce detectable SES at r≈100km. This model also indicates that SES can be detectable within certain areas *only*, thus explaining the *selectivity effect*.
Furthermore, it is shown that, for big earthquakes *only*, i.e., with M≈6.5-7.0, a magnetic field variation (B_z~1nT) becomes detectable simultaneously with SES.
This work is supported by the project EPET II-388

THE BIESCAS DISASTER: LIMITATIONS TO THE PREDICTION OF EXTREME EVENTS.

S. M White and J.M. García-Ruiz (Instituto Pirenaico de Ecología, Campus de Aula Dei, Apartado 202, 50080-Zaragoza, Spain)

On the evening of 7th August 1996 a violent thunderstorm occurred over the Arás catchment in the central Spanish Pyrenees. 87 people were killed, the main road was cut and considerable damage was done both within and downstream from the catchment. Subsequent analysis of return periods has identified several problems for the prediction of such events. Firstly, these storms, either convective or caused by a 'gota fria' (an isolated cold air mass within warmer air), although frequent in the Pyrenees, are extremely local in nature. The focus of the Biescas storm covered an area of only some 4 km^2. This means that, although there is a fairly dense network of raingauges in the central Pyrenees, storm rainfalls are often not recorded at any station. Secondly, the difference in maximum observed rainfall in a standard 30 year record at raingauges within 5km of one another can be vastly different, resulting in completely different estimates of return period for neighbouring gauges. Thirdly, it is not just the extreme rainfall which is the problem, but also the hydrological and geomorphological impacts of such events which are normally not considered in standard risk analysis for planning purposes. These points are discussed more fully in the light of the Biescas event, and other similar storms in past years.

A REVIEW ON THE STATISTICAL SIGNIFICANCE OF VAN PREDICTIONS

P. Varotsos , M. Lazaridou, K. Eftaxias and V. Hadjicontis (Solid Earth Physics Institute, University of Athens, Greece)

A Special Issue (*Geophys. Res. Lett. 23,* 1996) was focused on the question whether the VAN predictions outperform random chance. The majority of the participants of this Debate was selected to be critics against VAN, but Varotsos and co-workers accepted to participate and responded to the critical comments. VAN critics, including Geller [1996], share the same "*requirements*"; they decrease the success rate by 50%, while the alarm rate is reduced by a factor 4-5. Furthermore, these "*requirements*", when applied to an ideally perfect earthquake prediction method (which successfully predicts all earthquakes above a certain threshold, and does not issue any false alarm), lead to the following paradoxes (Varotsos et al. *Acta Geophysica Polonica*, vol. XLIV, n° 4, 1996): (a) the success rate is below 100%, (b) the alarm rate is 23% *only*, and (c) the ideal precursors are "postseismic" signals. Recent statistical treatments by Hamada (in *The Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals*, ed. Sir J. Lighthill, World Scientific Publishing Co., Singapore, 286-291, 1996) and by Aceves et al. (*Geophys. Res. Lett., 23*, 1425-1428, 1996) coincide to the conclusion that VAN predictions cannot be ascribed to chance.

PREDICTION OF THE 6.6 GREVENA-KOZANI EARTHQUAKE OF MAY 13, 1995

P. Varotsos, N. Sarlis, K. Eftaxias, M. Lazaridou, J. Makris and A. Abdulla. (Solid Earth Physics Institute, University of Athens, Greece)

Seismic Electric Signals (SES) were recorded by VAN group on April 18-19, 1995, at Ioannina station; they resulted in an official prediction that was sent (two weeks before the earthquake occurrence) to the Greek authorities as well as to various International Institutes (Varotsos et al., in *The Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals*, ed. Sir J. Lighthill, World Scientific Publishing Co., Singapore, 29-76, 1996).
The observation of these electrical variations was confirmed by Gruszow et al. (*Geophys. Res. Lett., 23*, 2025-2029, 1996); however, they claim that these signals could be attributed to a (non determined) nearby artificial source with huge intensity (IL≈$4x10^4$Am, for r≈2km, or $1.6x10^5$Am, for r≈4km). This claim is not valid, because, such a nearby source (cf. horizontal point current dipole) should have produced electrical field variations having amplitudes two orders of magnitude, larger than the observed ones; this is theoretically shown and experimentally verified.
The above SES obey the criteria, suggested by Varotsos and Lazaridou (*Tectonophysics 188*, 321-347, 1991), for discriminating SES from noise.
This work was supported by the project EPET II-388.

NH2 Techniques and tools for mapping natural hazards and risk impact on the developed environment

Convener: Guzzetti, F.
Co-Convener: Carrara, A.

ITALIAN LANDSLIDE HAZARD MAP: A CASE STUDY IN THE TEST AREA OF THE GRAMOLAZZO SUB BASIN (SERCHIO RIVER BASIN - TUSCANY, ITALY)

Marco AMANTI (PCM - DSTN - Italian Geological Survey, Via Curtatone 3, 00185 Rome - ITALY)
Pierluigi CARA (PCM - DSTN - Italian Geological Survey, Via Curtatone 3, 00185 Rome - ITALY)
Massimo PECCI (ISPESL - Productive Plants and Environmental Interaction Dep. (DIPIA), Via Urbana 167, 00184 Rome - ITALY)
Renato VENTURA (PCM - DSTN - Italian Geological Survey, Via Curtatone 3, 00185 Rome - ITALY)

Italian Geological Survey, in co-operation with ISPESL-DIPIA, is testing a methodology to produce landslide hazard maps (AMANTI et alii, 1992) and to evaluate natural risks in productive areas. The Serchio pilot project (183/89 Italian law) started in 1993; data collecting, digitising, analysing and processing have been partially performed till now, with the presentation of several case studies, related to particular areas and phenomena (AMANTI et alii, 1994, 1995, 1996a, 1996b). Automatic procedures using multivariate and probabilistic analysis in GIS environment have been performed after data validation and control: the results on a small test area are presented in this paper. The further and final step is the transfer of used and tested methodology to the whole studied Serchio river basin, aimed at the definition of "official rules" to produce the Italian landslide hazard map at a scale 1 :50.000.

THE USE OF GEOPHONES AS MONITORING AND WARNING SYSTEMS FOR DEBRIS FLOWS

M. Arattano and G. Lollino (CNR-IRPI, Strada delle Cacce 73, 10135 Torino, Italy)

Debris flows constitute a major threat for several urban settlements located on the fans of mountain catchments. Often structural measures such as the construction and maintenance of deposition basins, check dams, channel linings are both too expensive and not capable of completely guaranteeing the safety of the inhabitants. Therefore the individuation of functional, reliable and possibly not expensive warning systems should be pursued to increase the available tools to face this often devastating kind of phenomenon. The use of geophones for the determination of the size and velocity of a debris flow wave before its arrival on the fan will be discussed. In 1995 a set of four geophones was placed at a distance of about one hundred meters from each other along a straight channel reach of a debris flow torrent on the Eastern Italian Alps. The goal was to verify which information could be obtained through this type of device on the occasion of a debris flow occurrence. On July 5, 1995, June 22 and July 8, 1996 three debris flows occurred that were recorded by the four seismic sensors. The results will be presented together with a comparison with the information regarding the events obtained through other types of devices (ultrasonic sensors and video cameras).

THE PERNICANA FAULT (MT. ETNA, SICILY): AN EXAMPLE OF ENVIRONMENTAL HAZARD FROM CAPABLE FAULTING

R. Azzaro (CNR-GNDT c/o Istituto Internazionale di Vulcanologia, piazza Roma 2, 95123 Catania, Italy)
E. Vittori, L. Ferreli, A. M. Michetti, L. Serva (CNR/GNDT c/o ANPA, via Vitaliano Brancati 48, 00144 Roma, Italy)

Fault capability is the high probability of significant surface displacement in the near future generally, but not necessarily, associated to earthquakes. This concept is more useful to hazard analysis than the generic definition of fault activity. The Pernicana fault is located in the north-eastern flank of Mt. Etna, bordering to the north the most mobile sector of the volcano affected by flank instability processes. Its kinematics is dip to oblique normal along the uppermost segments near the NE Rift zone. To a lower altitude, the fault presents left-lateral motion. Earthquakes of low magnitude (<= 4.2) but high intensity with associated surface faulting (due to shallow focal depths) occur in the western sector of the fault whereas in the eastern one, downhill near the coast, aseismic creep seems to dominate. The case of this fault is effectual to illustrate the damage expectable from capable faulting, because of its continuous and high rate of slip and its location across urban areas. In fact, buildings, roads and other essential lifelines are affected by slow, left-lateral displacement determining severe damage and high risk in the near future. The Pernicana fault is only one of a set of tectonic structures in the Etnean area posing severe hazard in the densely urbanized territory north of Catania. Outside the Etna volcanic region fault capability is generally associated with high magnitude earthquakes (>= 6.5), based on historical and palaeoseismological data. This source of hazard, still poorly considered by local planners and technicians, must be taken into due account for hazard reduction programs.

Identification and Assessment of Natural Disasters: a risk based decision method

F. Baehler, Th. Peter, J. Diebold, Ernst Basler + Partners Ltd. Switzerland

Which natural disasters can threaten the Swiss society, what are the expected consequences, and what is the relative importance of these dangers? To answer these questions, a comparative quantitative risk analysis has been elaborated. In view of the broad range of dangers facing society and given the budget retrains, the overall assessment will improve contingency planning and helps setting priorities. Therefore the results provide basis for authorities and policy-makers who are thinking about the future and who need to make better choices - maybe a decisive step from theory to practice.

Prediction of extreme events in old platform:complex data of faults, fluid permeability,microtremors of the basement and sedimentary cover

Andrey B.Beklemishev,Vladimir G.Budanov,Oleg A.Potapov,Anatoly. P.Pronin VNIIGeofizika,VIMS,Moscow,Russia

Approaches,which consider the East European platform as a absolute stable,are corrected today.Here there are nonconsolidated zones(NCZ) with local high microtremors and fluid permeability(helium,hydrosulphur).Margin of NCZ is in compliance with deep faults,boundaries of protuberances and sharp forms of basement surface.As a result buil dings and communications near boundary of NCZ undergo destructively surplus affections,and their life time decreases sometimes dramatically.Our technology for data acquisition includes measuring of micro tremors by new"VIBROTESTER-MC"system,of fluid component concentrations in underground waters,readings different type gravimeters for tracing of faults,and seismic,deep well,hydrogeological,geomorphological data as well.Derivative maps of microtremors levels and frequency dominants,of fluid permeability of sedimentary cover in NCZ as well as the practice of buildings degradation allow to predict extreme events and to reveal localities,characterized by various fatigue or strength.

DETERMINATION OF FLOODING AREAS WITHIN URBAN PLANNING IN THE LOMBARDIA REGIONE - ITALY

A. Belloni, F. Milani, N. Padovan, M. Presbitero (Regione Lombardia, Milano, Italy)

F. Luino (CNR-IRPI, Torino, Italy)

The floods occurred in these years in Italy have emphasized the susceptibility of many urban areas towards river dynamic procesess. In order to provide flood risk mapping (scale 1:10,000 or 1:5,000) of the built-up areas and specific directions for urban planning, the Geological Survey of the Lombardia Region has started up a pilot study focused on the High valley of the Oglio River. The work has taken into consideration the following aspects:

1. definition of the river corridors, based on morphological, hydrogeological and hydraulic characteristics of the basin;
2. 2.careful research of historical events, usually stored from the different Local Public Offices in order to map flooded areas and highwater levels;
3. the evaluation of the principal man-made structures in the areas and of the water discharge and sediment load for all the tributary rivers and streams.

FLOODING OF PROPERTY BY RUNOFF FROM AGRICULTURAL LAND IN WESTERN EUROPE: RISK AND MITIGATION

J. Boardman (Environmental Change Unit and School of Geography, University of Oxford, 5 South Parks Road, Oxford OX1 3TB, UK)

In recent years the threat of flooding of property by runoff from agricultural land has greatly increased in western Europe. The costs of damage have been borne by individual property owners, local authorities, the water industry and insurers. Damage is due to the increase in area of arable farming especially high-risk crops such as maize, sugar beet and winter cereals; the creation of larger fields, the cultivation of steeper slopes , the deterioration in soil quality; and the expansion of urban areas into flood-risk zones. The importance of these factors varies from region to region. Areas that have been particularly affected by flooding problems include the Pays de Caux (northern France) , the loessic belt of central Belgium, the province of South Limburg (Netherlands) and the South Downs (UK). Response to the threat of flooding has been varied. Some areas have relied on emergency engineering works, usually the building of dams and diversion trenches: these have not always been successful. In other areas flood protection measures consist of local bylaws which restrict certain agricultural activities. The key to protection would seem to be land-use change targetted on at-risk sites. These can be identified relatively easily e.g. using GIS approaches. More difficult is to institute economic incentives to encourage farmers to carry our land use change. Policy mechanisms such as Set Aside could be used to reduce the risk of flooding.

EVALUATION OF FLOOD FREQUENCY IN THE MEDITERRANEAN REGION: A NEW APPROACH MERGING RESULTS FROM QUANTITATIVE METEOROLOGY AND HYDROLOGY

G. Boni, P. La Barbera and F. Siccardi (Environmental Monitoring Research Centre, Cadorna, 17100 Savona, Italy)

The region along the Mediterranean Sea includes steep orographic relief all alon g the coastline: small catchments drain this thin strip of territory. In the northern Mediterrane an regions the floodplains of these rivers are densely urbanised. By this reason coastal u rban settlements are exposed to high risk of flood: the main challenge is to mitigate the impact of floods on people and economic activities. In the developing southern regions the coast i s not yet densely urbanised, but the challenge is that to avoid the errors done in the policy of t he urban development of the northern regions. To start a correct policy of mitigation of the risk of flooding and to avoid urbanisation of areas higly exposed to this risk, an homog eneous definition of the criteria for the evaluation of the flood frequency is needed. The recent results obtained in the study of the characteristics of the Mediterranean storms allow some innovation in the methods for flood frequency evaluation. The new method is presented, which includes the possibil ity to directly obtain the expression for the areal reduction factor. The method allows to get the mean areal rainfall as a function of easily observed meteorological and geomorphologic parameters. The application of the method provides the peak flow discharge for a population of catchements in a region, for a given return period, provided that the region is sensibly meteorol ogically and geomorphologically homogeneous

THE TOOLS FOR MONITORING OF MAGNETIC PRECURSORS OF SEISMIC HAZARDS

R.Berkman, V.Korepanov (Lviv Centre of Institute of Space Research, Naukova str., 5-A, 290601, Lviv, Ukraine)

Last time the idea of the existence of electromagnetic (EM) precursors of such seismic hazards as earthquakes and volcano eruptions is widely supported. Both electric and magnetic components of the EM radiation are experimentally studied and each component reflexes its own side of the corresponding physical phenomena. Because of very low level of these signals the problem of obtaining as low as possible sensitivity level is one of the most important. It is difficult to give some advantageous recommendations as to the noise reduction of electrical measurements . But for magnetic ones last improvements in search-coil magnetometers (SCM) design and manufacturing give hope both to decrease considerably the noise level of the sensors and to rise their interferencies rejection ratio. A set of wide-band and narrow-band SCM covering the frequency range from 0.0001 Hz to 500 kHz is described together with some new possibilities of noise reduction and interferencies suppression. The possibility to get the noise level less than 1 femtoTesla and to suppress more than 120 dB the interferencies is discussed. Experimental sensitivity curves of the developed SCM are presented.

EARTHQUAKE-INDUCED VARIATIONS IN THE COMPOSITION OF THERMAL WATERS ON VULCANO ISLAND, ITALY

L. Bolognesi (CNR-International Institute for Geothermal Research, Piazza Solferino 2, 56126 Pisa, Italy)

On Vulcano Island, in southern Italy, numerous shallow water wells have been drilled for domestic use at the foot of the active crater. The thermal water in the well which supplies water to the camp-site Camping Sicilia is a mixture of reservoir water and shallow steam-heated groundwater of meteoric origin. During 1986-1988, the only variations observed in the available isotopic and chemical compositions of the Camping Sicilia well water, which changed from the almost pure reservoir component to the almost pure steam-heated meteoric component, occurred just before two sequences of tectonic earthquakes recorded near the island. After the seismic activity, the Camping Sicilia well water returned to its pre-earthquake composition. These changes in composition could be explained by the dilatancy-fluid diffusion model. According to this model, the observed variations in the Camping Sicilia well water composition could be the consequence of stress build-up prior to the seismic events, and stress reduction afterwards.

A NEW METHOD FOR THE EVALUATION OF THE FLOOD RISK. CASE STUDY: THE WESTER N PART OF THE LIGURIA REGION OF NORTHERN ITALY.

G. Boni, L. Ferraris and P. La Barbera (Environmental Monitoring Research Centre, Cadorna, 17100 Savona, Italy)

The Liguria region belongs to the thin strip of territory along the northern Med iterranean coastline characterised by catchments presenting small extension with floodplains densely urbanised. In these areas, public administrators are involved on the redefinition of the policy of t he development of the urban settlements sensible to the problem of the risk of inundation. A correct e valuation of the magnitude of the flood frequency is necessary for this purpose to help the plann ers in mapping the areas exposed to the highest risk of flooding and to take correct decisions in t heir policy. A new method for the evaluation of the flood frequency is applied here to the western part of the Liguria region in order to obtain an homogeneous evaluation of the magnitude of the peak discharge for a given return period. The method is based on the recent results in the field of t he study of the characteristics of the Mediterranean storms. The results are shown and a validat ion of the method, using data from monitored basins and traditional flood evaluation techniques, is performed.

THE GEOCHEMICAL SEISMIC ZONATION: A GIS MULTIDISCIPLINAR APPLICATION FOR SEISMIC SURVEILLANCE

C.A. Brunori and F. Quattrocchi, E. Boschi, F. Buongiorno, M. Calcara, F. Doumaz, M. Guer ra, G. Mele, P. Montone, L. Pizzino, S. Salvi (Istituto Nazionale di Geofisica, Rome, Italy)
S. Lombardi, F. Zampetti (Universita di Roma "La Sapienza", Rome, Italy)
R. Funicello, F. Salvini, A. Billi (Universita "Roma III", Rome, Italy)
M. Angelone (Lab. ENEA AMB-TEIN-CHIM)
M. Zuppi (Universita di Torino, Italy)
B. Marty (CNRS Nancy, France)

The GEOCHEMICAL SEISMIC ZONATION Project (EC contract ENV4-CT96-0291) is carried out by a multidisciplinary integration of different data sets. The main goal of the project is to assess the contribution of fluid geochemistry to the Seismic Hazard Assessment (SHA), i.e. the recognizing of active faults in different geological environments. The Gargano test site (Central Italy) has been the first area studied up to date: four geochemical surveys were performed with the main task to differentiate either active and non-active fault systems. Structural geology new data set relative to a few fault segments selected over the Gargano area has been collected, on meso scale, in correlation with satellite images. Geochemical time series of two selected sites are cross - correlated with present seismicity.
The management of the different data sets is being performed by GIS techniques (ARC/Info software-ESRI Inc.). The GIS structure, allows a very fast storage, update and analysis of the different data sets.

GIS-BASED ACTIVE FAULT IDENTIFICATION AROUND THE CITY OF IZMIR IN WESTERN TURKEY

R. Cakir and S. S. Alexander (Department of Geosciences, The Pennsylvania State University, University Park, PA, USA)

As the basis for quantitative seismic hazard assessment around the city of Izmir in western Turkey, reliable data relating past earthquakes to active faults in the region is essential. Towards that goal this study combines available earthquake data in the form of seismicity and focal mechanisms, past geological and tectonic studies of geologic structure and faults, deformation from ongoing Global Positioning System (GPS) experiments, and remote sensing imagery (Landsat Thematic Mapper) in an integrated GIS database. As shown in this study, the GIS approach facilitates the interpretation of spatial relationships among these observations and increases the likelihood of identifying and correctly characterizing active faults that may contribute significantly to the seismic hazard of this region. Other important information to be added later to the GIS database includes expanded remote sensing coverage; maps of frequency-dependent attenuation of ground motion; distribution of shallow, surficial deposits that can significantly amplify ground motion at certain frequencies; and infrastructure at risk from earthquake groun motion. This integrated GIS database will then be used to carry out probabilistic or deterministic seismic hazard and risk assessments for Izmir and neighboring populated areas.

LANDSLIDE RISK PREVENTION AND MANAGEMENT IN THE NORTHERN APENNINE

Paolo Canuti, Nicola Casagli, Filippo Catani and Alberto Iotti (Dipartimento di Scienze della Terra, Universita di Firenze, Via La Pira, 4, 50121 Firenze. Italy)

This note describes some techniques for evaluating the landslide impact on developed areas and the countermeasures adopted for risk prevention and emergency management. The presented methods are based on the guidelines recently proposed by the National Group for Hydrogeological Disaster Prevention (GNDCI) for the preparation of "Plans of Landslide Forecast and Prevention". Examples are drawn on some emergency events occurred between 1992 and 1996 in the Tuscany and Emilia-Romagna regions. The complete risk assessment requires the separate evaluation of landslide hazard and of the potential worth of losses. The application of GIS techniques for the first case is well known in the scientific literature. This note describes in particular some examples of application of GIS for the forecast of the possible consequences of mass movements, in course of event, taking in special account cases of induced risk, as those which occur from the interaction of slope movements with river channels. The use of GIS allows us to define different scenarios of evolution of the danger and to associate to each one a cost in term of loss of properties and human lives at risk. Each scenery is defined on the basis of some indicators measurable with field surveys or with monitoring systems. The different scenarios can be analysed in probabilistic terms with reference to a probability tree. From the assessment of conditional probabilities, based on experience and on a series of similar events, it is possible to assess the probability of occurrence of each risk scenery. Knowing the economic value associated to the different elements at risk it is possible to assess completely the total risk. For each scenery the activity of first intervention can be scheduled, aimed to the reduction of the vulnerability of the elements at risk and to the consequent mitigation of damages.

OMBINING OPTICAL AIRBORNE IMAGE DATA AND TMOSPHERIC MEASUREMENTS TO ENSTIMATE AND MAP)2 IN TROPOSPHERIC VOLCANIC PLUMES

.F. Buongiorno (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, Rome, ly)
.P Bogliolo (Istituto Nazionale di Geofisica, Via di Vigna Murata 605, Rome, ly)
Teggi (Osservatorio Geofisico dell'Universita' di Modena, Via Campi 213/A 100 Modena, taly)
'ugnaghi (Osservatorio Geofisico dell'Universita' di Modena, Via Campi 213/A 100 Modena Modena, Italy)

e study of tropospheric volcanic plumes formed by the continuous degassing from nmit craters could provide informations on the magma moviments in the canic conduit. To investigate the volcanic plume composition a direct sampling hnique, although producing good results, requires a considerable logistical nning and in some cases personal risk. The SO_2 molecula shows absorption tures in U.V., thermal I.R. and microwave regions of the EMS, which could be estigated with remote sensing systems. The present study is based on a thodology developed on airborne remote sensed images acquired by the TIMS rument (Airborne Thermal Infrared Multispectral Scanner images) over Mt. Etna. `4 the Italian CNR organized the first MIVIS (Multispectral Infrared and Imaging Spectrometer) deployment in Sicily on a variety of test sites. We l to test and improve the SO2 retrieval technique on the MIVIS data acquired a by combinig the remote sensed images with accurate atmospheric and measurements.

SO_2 flux measurements at Mt. Etna using a correlation spectrometer COSPEC and a new real-time elaboration system

Caltabiano Tommaso, Romano Romolo and Bruno Nicola
Istituto Internazionale di Vulcanologia - C.N.R. - Catania - Italy

A new system of acquisition and elaboration has recently been developed for data that are systematically acquired with a correlation spectrometer COSPEC on the SO_2 flux of active Sicilian volcanoes and in particular Mt. Etna.
The COSPEC is connected to a portable Personal Computer that uses an A/D (analog-to-digital) conversion card to collect the signals from the spectrometer. A GPS system gives the information on the geographic position during the measurements. This system allows the real-time measurement of SO_2 flux data corrected both for the scanning path-way and noise induced by eventual interference. During the measurements this system constantly shows the SO_2 concentration present in the field of view of the spectrometer and the value of the SO_2 flux calculated up to that point of the scan. The user-system interface has been designed to make the use of the system as easy and as friendly as possible and to avoid eventual operator errors. This acquisition system, easily transportable and extremely compact, immediately gives the data already elaborated and is thus very useful in the monitoring and prediction of volcanic activity. In this work the tests used to set up the system carried out on Mt. Etna are presented.

CURRENT TRENDS IN COPING WITH NATURAL DISASTERS

A. Carrara (CNR-CSITE, Bologna, Italy)
M. Cardinali, F. Guzzetti and P. Reichenbach (CNR-IRPI, Perugia, Italy)

Nowadays, a great expectation exists on potential of the new technologies in coping with natural disasters. Since industrialised societies are increasingly less eager to invest a great deal of money to reduce natural risks by means of structural measures, the new issue consists in the development of warning systems which should minimise the loss of lives without long-term investments.
Several popular misconceptions were then borne and spread out. A landslide hazard map which was obtained through GIS operations, is often assumed to be more objective than a comparable hand-made product attained with the same input data and founded on the same conceptual model. A great expectation is placed on the exploitation of satellite imagery and ground wicrowave systems for timely forecasting extreme rainfall events. The reality seems to be somewhat less than those optimistic hopes. Investigators are investing more in tuning up hazard models founded upon existing, ill-reliable data than in attempting to initiate long-term, academically ill-rewarded, projects for the acquisition of new basic information on the causal factors of catastrophic events. Governmental institutions are frequently involved in risk reduction projects whose design and implementation appear leaded more from political issues than technical ones. There is a general unwise tendency to search for data which can be collected at low cost than to attempt to capture those which are most related to the causes of catastrophes. If the economic, political and cultural causes of this unhealthy state cannot be removed, the International Decade for Natural Disaster Reduction will likely end without significant advancements in the prediction and control of natural disasters.

A GIS FOR VOLCANIC RISK AT VESUVIUS

L. Cavarra and M.T. Pareschi (CSGSDA-CNR, v. S. Maria 53, I-56100 Pisa, Italy)

The Vesuvian area (near Naples, Italy) is potentially one of the most risky ones worldwide: some municipalities have a population density similar to that of Honk Kong, and the country is "dominated" by the Vesuvius volcano, quiescient today, but presenting, along its long history, ruinous explosive eruptions. In this context it is extremely useful to Civil Protection an "inventory" of the resources, that is a GIS of the area around Vesuvius.
Here we present a GIS for the Vesuvian area containing digital information about elements having spatial connotations. The area concerns 18 municipalities, with a total extension of about 235 km^2. The scale of the photo-restitution phase was 1:5,000. In the database each territorial datum (object) is defined by a set of georeferenced basic elements: points, lines, polylines, areal elements.
The territorial objects are organized according to different themes (layers), in turn enclosed in a smaller number of "families". For example the family "electricity" includes the layers electrical lines, pylons, stations, etc. The layers are more than a hundred and all the layers of a given family are displayed on the screen using the same colour. Each object of the data-base is described by alphanumeric information too (for example buildings are characterized by the seismic vulnerability and volcanic hazard, according to the place where they are located), which can be used to guide selective displays. The graphical representation of all the objects follows a dimensional criterion, according to which, only the parts of the object greater than a suitable dimension are represented.
The hardware utilised is an IBM RISC6000 MODEL 540, 128 RAM Mb, internal HD 2Gb, 21" 24bit video, 1280x1024 resolution; the software is GEOMAX-XM.

TECHNIQUE AND DEVICE TO MEASURE CS-137 SOIL DEPOSIT CHARACTERISTICS IN-SITE

A.V. Chesnokov, A.P. Govorun, O.P. Ivanov, V.I. Liksonov, S.V. Smirnov, V.N. Potapov, V.N. Fedin, S.B. Shcherbak, and L.I. Urutskoev,
RECOM Ltd., RSC "Kurchatov Institute"

The technique to determine Cs-137 soil deposit in site is described. It is based on a processing of gamma energy spectrum measured by a collimated gamma spectrometric radiometer (CSR). The thickness of analyzed layer is 3 mean free path (mfp) of Cs-137 radiation in the soil. The technique allows to determine a thickness of upper soil layer containing more then 80% of a total Cs-137 stock. The thickness of uncontaminated soil layer covering a contaminated one may achieve 2mfp. The new portable CSR was developed for measurements. The detectable soil deposit minimum of CSR is 20 kBq/sq.m and accuracy is near 15%. The data obtained for contaminated territories in former USSR shows good agreement with results of traditional measuring methods. The developed technique is effective for landscape gamma radiation survey because of its simplicity and high productivity. The CSR measurements of activity density of natural nuclides (Ra-226, Th-232, K-40) and manmade ones (Eu-154, Co-60) show its efficiency for study of mine wastes and complex gamma-nuclides contamination. The river's bank contamination anomaly were investigated. It was shown that the high contaminated areas of bank territory exist due to gathering of deposit from water surface. The high spatial resolution and possibility to measure the contamination penetration depth allow to make scale analysis of deposit and to distinguish the initial contamination from secondary one (result of human activity).

PREDICTION MODELS IN SPATIAL DATA ANALYSIS FOR GEOLOGIC HAZARDS

C. F. Chung (Geological Survey of Canada, 601 Booth Street. Ottawa, Ontario, Canada K1A 0E8)

To construct prediction models for geologic hazards using GIS-based spatial data, three mathematical frameworks, namely probability theory, Zadeh's fuzzy set theory and Dempster-Shafer's evidential theory, have been studied. The models have been built to incorporate both the expert's knowledge and the quantitative relationships between the past occurrences of geologic events and the supporting spatial data. In addition, several comparison and evaluation techniques have been developed to test and validate the performance of the models as prediction tools identifying vulnerable areas for the occurrence of future geologic hazardous events. A landslide hazard study in the Rio Chinchina area in Colombia is used to illustrate the techniques proposed.

EVALUATION OF QUANTITATIVE PREDICTION MODELS FOR LANDSLIDE HAZARD.

C. F. Chung (Geological Survey of Canada, 601 Booth Street. Ottawa, Ontario, Canada K1A 0E8)
S. Obayashi and H. Kojima (Science University of Tokyo, 2641 Yamazaki, Noda, Chiba, 278 Japan)

Quantitative prediction models for the occurrences of future landslides are based on the quantitative relationships between the past landslide occurrences and several layers of spatial map data which are known to be "latent" factors of landslides. To evaluate a performance of a prediction model for future landslides, the corresponding quantitative relationship from which the model has been built, should be robust with respect to time. We have investigated the time-robustness of prediction models in Rio Chincina Study area in Colombia, by dividing the distribution of the occurrences of the landslides in the study area into two groups, (i) Pre-1960 consisting of the landslides occurred prior to the year 1960; and (ii) Post-1960 consisting of the landslides occurred from 1961 to 1988, and then studying quantitative relationships of these two groups and the spatial map data. We have considered three prediction models, "Direct method", "Fuzzy set theory using algebraic sum operator" and "Bayesian probability method". For each model and each group, "success" rates indicating how well the model performed with respect to the occurrences in the group and "prediction" rates with respect to the occurrences in the other group which has not been used to construct the model. The prediction rates of the models are highly correlated with the time-robustness of the models.

FORECASTING AND PREVENTION OF CONTAMINATION OF GROUNDWATER RESOURCES FOR HUMAN SUPPLY USING GIS TECHNOLOGY.

M Civita (Dip. Georisorse e Territorio, Politecnico di Torino, C.so Duca degli Abruzzi , 24 - 10128 Torino, Italy)
M De Maio (Dip. Georisorse e Territorio, Politecnico di Torino, C.so Duca degli Abruzzi , 24 - 10128 Torino, Italy)
G. Manelli (ESRI Italia Via Tiburtina, 755 - 00159 Roma, Italy)

A new methodology (Civita, 1995) for the assessment and zoning of groundwater quality degradation risk have been proposed and tested starting from the point of view of interaction of all the potential and effective contamination sources to all risk targets within the some country frame.The method implemented by a GIS gives in real time a number of thematic maps and at last a groundwater contamination risk map. The processing procedure give all connection scenarios of the underground hydrogeological system and its sensitivity to contamination (Vulnerability, effective flow direction and time of travel, etc.) to the geographical position and the groundwater contamination potential of contamination source centre (CSC). The contamination risk map is built starting from the following three points: the sensitivity of the system to be impacted, the statistic probability of the contamination impact and the severity of the waited damage.
The methodology and its implementation by GIS as been tested in several zones within a scientific research program of Italian Council of Research.

NATURAL CATASTROPHE EMERGENCY RESPONSE: USE OF GIS POST-EVENT DAMAGE TOOLS

Jean-Paul Conoscente, EQE International

In the immediate aftermath of a major damaging natural catastrophe, local governments, insurance companies and other private sector organizations face the difficult task of rapidly allocating life safety services and identifying severely damaged structures, particularly damage to critical facilities. In the past, this task has often been characterized by a lengthy period of reconnaissance during which inaccurate reports, distortions, and rumors must be separated from factual disaster intelligence painstakingly gathered from multiple sources.
The utilization of loss estimation techniques, including near real-time estimations of building, and lifeline damage and casualties associated with a GIS mapping system is a key to efficient emergency response and early recovery decision making in the immediate post-event context. An example of such system developed by EQE International is presented. The system utilizes real-time seismic information, digitized soil information and damage and casualty estimation models and was used by the California Office of Emergency Services in the aftermath of the 1994 Northridge earthquake. Such systems are applicable in all countries subjected to earthquakes and other damaging natural perils, such as floods, hurricanes, tsunamis and volcanic eruptions.

FORECASTING LAVA RISK FOR THE ETNEAN AREA BY CELLULAR AUTOMATA METHODS OF SIMULATION

G.M. Crisci°, S. Di Gregorio^, F. Nicoletta*, R. Rongo^, W. Spataro^
°Dip. di Scienze della Terra ^Dip. di Matematica *Dip. di Chimica
Università della Calabria, I 87036 Arcavacata, Italy

The models SCIARA-1 and SCIARA-2, based on the Cellular Automata, are a very potent and versatile instrument whose scope is to reduce volcanic risk from lava flows; the possible fields of intervention are:
a) long term forecasting of the flow direction at various eruption rates and points of emission by locating potential risk areas and permitting the creation of microzonal maps of risk involved;
b) the possibility to precisely follow the progress of an event and predict its evolution in great detail;
c) the verification of the possible effects of human intervention on real or simulated flows in stream deviation.
Corresponding to a) and c) we individuated a risk scenario for the Etnean territories of the towns of Nicolosi, Pedara and S. Alfio.
This area was selected because it is closed to the end of the fracture opened in the 1989 eruption and successively activated in 1991-2 eruption. Hundreds of possible episodes have been simulated with different vent locations and have been individuated the main characteristics of lava flows dangerous to the developed environment.

ON IMPROVEMENT OF NATURAL DISASTER WARNING SYSTEM

Geng Dayu & H.W.Weinmaister

A new model of natural disaster warning system composed by four subsystems as put forward: 1, Detective subsystem including monitoring section, assessing section and prediction section; 2, Management subsystem including interpret section, decision making section and modifying section; 3, Response suvsystem inclufing response channels, individual response and public response; 4, Feedback subsystem including real-time data section, comparing section and feedback section. For each subsystem some special improvements were put forward: 1, Application of GIS, GPS, remote sensing and database; 2, Special training programs should be offered to different kinds of people; 3, Feedback sybsystem should become an essential part of the warning system with high-tech methods; 4, International communication and cooperation should be improved in order to set up global natural disaster warning system. Some successful experiences and failure lessons on warning system in the world were exampled.

RADON MIGRATION IN THE SOLFATARA CRATER, CAMPI FLEGREI.

S. De Martino, M. Mattera, G. Monetti, C. Sabbarese (Dipartimento di Fisica, Universit di Salerno, I-84081 Baronissi, Salerno, Italy)

Radon migration was studied in the soils of the Solfatara Crater, Campi Flegrei (Southern Italy) using radioactive disequilibrium between Ra-226 and Pb-210. Vertical profiles of soil (as far as 5 m long) were investigated. Radon migration parameters were studied as function of physical characteristics of soil (density, porosity, grain size, water content) and also by considering the fumarolic emissions, the small crater of hot mud and the small fault present in the crateric area. Results show: 1) the good sensitivity of disequilibrium method at the physical variations of the soil; 2) the influence of the transport velocity as function of the distance from the fumarolic emissions, from the small fault and from the hot mud; 3) a global model of radon migration in the soils of the crateric area, which presents interesting results respect to the temperature and permeability gradients.

PIEZOMAGNETIC EFFECTS INDUCED BY ARTIFICIAL SOURCES ON MT. VESUVIO (ITALY)

Ciro Del Negro and Rosalba Napoli (Istituto Internazionale di Vulcanologia, CNR, Piazza Roma 2, 95123 Catania, Italy)

Traditionally, ground deformations and seismic activity studies are used to detect the precursory signals of volcanic eruptions. Both methods point out local phenomena such as a rupture along a fault plane or local deformations along a fissure system. Therefore, these techniques can be usefully supported for monitoring volcanic activity by the magnetic method which integrates the effect of a phenomenon over a large volume. However, verification of the possibility of measuring changes in the magnetic field associated with volcanic activity has been going on for a long time.
In order to prove the existence of vulcanomagnetic effects associated with mechanical stress, measurements in continuous of the magnetic field were executed during the three-dimensional seismic tomography carried out at Mt. Vesuvio. In some cases, remarkable changes in the intensity of the magnetic field in correspondence to explosions were observed.

GIS TECHNIQUES FOR MAPPINGGROUNDWATER CONTAMINATION RISK.

Daniela DUCCI Istituto di Geologia Applicata. Università di Napoli. Italy.

The groundwater contamination risk map at a medium scale (1:50.000) of a sample alluvial area has been produced. The parametric method for pollution risk assessment proposed by Civita (1995) has been adopted. According to this approach to evaluate the ground-water pollution risk, the hazard, which is function of time, is substituted by the "danger", function of the spatial distribution of the contamination sources. The damage is quantified as the product of the impact subjects vulnerability by the value. The risk map is obtained crossing the thematic maps. The geographical information system ILWIS has been used to construct and to overlay the thematic maps, with pixel size of 30 x 30 m. For instance the processing to construct the ground-water quality map were carried out in a GIS environment, applying the method described by the author in a previous paper (Corniello *et alii*, 1995).
The procedures used to evaluate the risk by Civita were partially modified considering the whole aquifer as the impact subject and only the catchments as the value, according to the hydrogeological setting and the adopted scale.
The use of a GIS permitted, by the developement of analytical procedures, to optimize the groundwater contamination risk assessment method, hrough: - high spatial resolution; - numeric checking of calculated arameters; - easy matrix operations.
he GIS technique proposed needs to be refined by testing and improving he method in various hydrogeological environments.

MAIN FACTORS CONTRIBUTING TO THE SEISMICITY, DISTRIBUTION OF PEAK GROUND ACCELERATION AND EARTHQUAKE DAMAGE IN EGYPT

A. El-Sayed, R. Wahlstr & O. Kulh nek (Seismological Department, Uppsala University Uppsala, Sweden)

Egypt has been shaken by several destructive earthquakes in both historical and recent times from distant and near earthquakes. The interaction of the African, Arabian and Eurasian plates, and the Sinai subplate, is the main factor behind the seismicity of Egypt. Earthquakes in Egypt occur at shallow depth and are concentrated to four seismic zones. The annual energy release is equivalent to an earthquake with mb varying from 4.5 to 7.0. Periods of high activity have a short recurrence time period, approximately 10 years. In Egypt, both small local and large distant earthquakes have caused huge damage. Poor building quality, low preparedness, shallow focal depth and local geological conditions are main factors contributing to the earthquake damage. Loose soft sediments amplify the peak ground acceleration by a factor of two. Water-saturated sediments causing liquefaction add to the earthquake damage. Highly populated cities, sensitive structures and archeological sites are located on a soft, water-saturated sedimentary ground. The expected peak ground acceleration in these areas in 50 years exceeds 0.1g.

TECTONIC ACTIVITY AND HIGH SITE EFFECT NEAR CAIRO CITY, EGYPT

A. El-Sayed, R. Arvidsson & Ota Kulh nek (Seismological Dept, Uppsala University, Uppsala, Sweden)

On October 12, 1992, an earthquake with magnitude mb = 5.9 and Ms = 5.2 occurred close to Cairo city, Egypt. It was one of the largest earthquakes in Egypt during this century. Destruction associated with this earthquake is concentrated to Cairo city, the Nile Valley and the Nile Delta areas. Similar destruction due to near as well as rather distant earthquakes were reported in Cairo city in the historical time. The return period for events with mb > 5 in Cairo area is 100-200 years. The 1992 earthquake shows a normal faulting mechanism with a strike slip component. The mechanism is compared with those corresponding to two events that occurred previously at the most northern part of the Red Sea. The similarity between the mechanisms as well as the spatial distribution of the geological faults around Cairo city suggest an existence of seismic activity along the extension of the Red Sea rift system to the neighbourhood of Cairo. Consequently, the level of hazard in Cairo is relatively high. Synthetic accelerograms calculated for the 1992 earthquake, show maximum acceleration of 0.55g at an epicentral distance of 10 km, but attenuate rather rapidly with distance. The value of 0.55g is relatively large with respect to the size of the earthquake and is a clear effect of loose sedimentary layer on top of the crust beneath the meizoseismal area. By ignoring the loose sedimentary layer, the maximum peak ground acceleration dropped to 0.35g at the same distance. The similarity between areas of strong shaking for the 1303 and 1992 Cairo 1992 earthquakes lead to a conclusion of proximity of hypocenters of the two events.

ASSESSING POTENTIAL CONTAMINATION OF GROUNDWATER FROM PESTICIDES WITH GIS TECHNIQUES

F. Facchino, Dip. Scienze dell'Ambiente e del Territorio, Univ. di Milano
G. Giuliano, I.R.S.A. - C.N.R., Roma

A procedure for assessing the pollution potential of pesticides for groundwater is proposed, which is suitable to be applied within a GIS environment.
The approach integrates the climatic, geopedological and hydrogeological features of the site with the chemodynamic behaviour of the polluting substances. Since it deals with a non-point type pollution source, the assessment is referred to unit vertical profiles, each one including soilzone, unsaturated zone and aquifer.
Vulnerability and potential contamination indices are obtained through a matrix combination of the ranked values of pesticides migration parameters, i.e. travel time, leaching quantity, aquifer dilution, expected contaminant concentration in groundwater. The areal distribution of the indices is represented in raster maps.
The procedure is applied at the same scale of detail in two sample areas of northern Italy, in order to test its adaptability to different types of hydrogeological settings. An evaluation of the results is given with reference to the actual state of groundwater quality.

Geoinformation Technology for Seismic Hazard Assessment and Earthquake Prediction Research

V.Gitis
Institute for Information Transmission Problems, RAS,
B. Karetny Lane., 19, Moscow, GSP-4, 101447 Russia, GSP-4,
FAX +7-095-2090579, E-mail gitis@ippi.ras.ru

Geoinformation technology named GEO provides efficient intelligent support in sophisticated geological and environmental applications such as seismic hazard assessment, earthquake prediction, environmental zonation, mineral, oil and gas exploration etc. Solution of these problems needs to process a wide range of space-time data and expert knowledge in order to find an empirical regularity as the basis for forecasting. The technology implemented in GEO integrates the GIS with artificial intelligence technologies. GEO supports two types of forecasting problems: static and dynamic forecasting. In the static forecasting some properties of geological medium or environment not depending on time are predicted. In the dynamic forecasting the time of occurrence of some catastrophic event have to be predicted. Examples of application on seismic hazard assessment and earthquake prediction are discussed.

TRANSLATIONAL BLOCK-TYPE SLOPE MOVEMENTS IN THE AUSTRIAN-LIMESTONE-ALPS

Juliane Heiland (Institute of Rock Structure and Mechanics, Czech Academy of Sciences, V Holešovičkách 41, CZ-18209 Prague 8, Czech Republic)

In this paper will be described the results of detailed geological, geotechnical and geomorphological mapping in two areas showing translational block-type slope movements. Both areas are located in the Austrian Alps in similar geological settings, one in the vicinity of Salzburg, the second near Bad Ischl. In both cases finegrained limestones of the liassic "Oberalm beds" are creeping on underlying weaker beds or on clayey intercalations due to gravitational forces existing in a dip slope. It is very interesting that in one area the shear zone is situated in the higher parts of the "Ruhpolding beds" which consist of thinbedded, flinty marls. These rocks are considered to have a very high strength, but due to their intense fracturing and content of clay-minerals their shear strength is very low. In both areas the developped gaping fissures are strongly determined by tectonical prediposed planes and in one case the morphology is superimposed by karst phenomena. The start of the movements is probably connected with the glacier retreat in the postglacial period and the total amount of movements until now is more than 10 m. The depth of the creep zone isup to 15 m.

A FIRST ATTEMPT BY THEMATIC MAPPING TO ASSESS THE HAZARD AND RISK OF LAVA FLOW INVASION IN THE EASTERN FLANK OF MT. ETNA VOLCANO (SICILY, ITALY)

R. Ieni, R. Rasà, R. Tripodo (Dipartimento di Fisica della Materia, Università di Messina, Salita Sperone,31, 98166 Messina - Italy)
L . Villari (Gruppo Nazionale per la Vulcanologia, Via Nizza,128, 00198 Roma - Italy)

Hazard assessment and risk evaluation of lava flow invasion on the highly urbanised, low-eastern slopes of Mt. Etna have been preliminary approached by cartographic methods aiming at producing data *which can be used* for assessing the sustainable urban development in this sector of the volcano and civil protection purposes. A lava invasion frequency map has been realized by interpolating a complete catalogue of 33 revised lava flows under 1000 m. asl maps starting from 1228 as well as a land use map of the same area by satellite imageries including the main lifelines. The initial results revealed that the cross-correlation of these maps emphasises that shape and location of the maximum invasion zone mimic the most urbanised area. This leads to a preliminary, albeit crude, assessment of the very high level of volcanic risk in the event of an eruption accompanied by lava flowing downward in the eastern flank of this very active basaltic volcano.

ALARM SYSTEM FOR MARINE ECOLOGICAL DISASTERS BASED ON THE REMOTE SENSING CONTROL IN THE AZOV-BLACK SEA REGION.

Ivanov L. M., T. M. Margolina and S. V. Stanichny (Marine Hydrophysical Institute Ukrainian National Academy of Sciences, 2, Kapitanskaya St., Sevastopol 335000, Ukraine)

The system of early warning for marine ecological disasters based on modern satellite technologies of data collecting in the Azovo-Black Sea Region is developed. The satellite images of the Black Sea and the Azov Sea in the optical, the infrared and the SHF diapasons from the NOAA, the Sich-1 and the Meteosut are applied to:

the estimation of a danger and scales of possible marine ecological disasters;

the prediction of tendencies in its development;

the producing of an information database for control and lawing desicions utilized by the Ukrainian government structures for the reduction of negative disaster conseguences and a covering of caused damage.

Integrating energy line concepts into a grid model for avalanche runout zone mapping

KLEEMAYR K.; PLATZER M., SIMMA S. and G. VOLK

An energy line based avalanche run out model (ELBA) combining statistical and physically based components has been implemented into a raster GIS. Due to the fact that the snow physical p rocesses taking place in an avalanche cannot be described yet the energy losses of an avalanche on its path down the slope are calculated stochastically by adapting the energy line concept. In contrast the information of the terrain where an avalanche is taking place can be quite detailed since we can use digital elevation models. Therefore the effects of the terrain on the flowpath of an avalanche can be modelled in a deterministic way by applying the laws of linear momentum on a geometrically exact flow algorithm in a grid based model. The model has been tested in Austria and Northern Italy. The results exhibited very good coincidence with historical data concerning the runout length as well as the trajectories of the simulated avalanches.

A STUDY OF FRACTAL DIMENSIONS OF LANDSLIDES AND NEURAL NETWORK SUSCEPTIBILITY ANALYSIS

Tetsuya KUBOTA, Tottori Univ., TOTTORI, 680, JAPAN

Topographical and geological factors have been used in order to find out landslide susceptible area. In this study, Fractal dimension of landslides is discussed as a topographical factor to express landslides complex topography for investigation of susceptible areas. Considered the self-affinity of landslide landform, Fractal dimension of landslides "D" is found, by multi-discriminant analysis, to be an index of landslides susceptibility. In this situation, "D" is applied to neural network computer system(NNW) with geological condition(formation etc.) and relief energy "RE" which was demonstrated as a susceptible factor. Then, landslide susceptibility can be judged automatically by NNW as the value of "D estimated", using "RE" and geological point "G" that is given to each geological group (or formation) decided by its average "D". The result of NNW judgment for example area is successful.

GIS AND ARTIFICIAL INTELLIGENCE FOR LANDSLIDE MONITORING

Marco Lazzari & Paolo Salvaneschi, ISMES S.p.A. - via Pastrengo, 9 - 24068 Seriate BG - ITALY

We present an application that exploits a geographic information system as a front-end of a complex information system supporting the management of landslide hazard in Northern Italy (Valmalenco, Val Torreggio, Val Pola).
A decision support system (EYDENET), incorporating a GIS and a data interpreter based on artificial intelligence techniques, processes the readings of the 250 most significant instruments of a monitoring net of about 1000 sensors installed on different landslides in several alpine valleys.
EYDENET, which has been operational since October 1996, provides on-line interpretation of these data, helps the users analyse them, and generates alarm messages for the people responsible for the environmental management and the civil protection.
We have integrated a GIS into EYDENET to exploit its cartographic facilities and offer a powerful representation tool to *navigate* through data. In the cartographic window EYDENET shows maps of the monitored areas and represents on them the different instruments through coloured lights, using a colour scale based on their state. Moreover, cartographic layers may be used to represent the activation state of physical processes and the hazard level for the zones affected by them.

A NEW ENVIRONMENTAL DATABASE FOR VENICE AND ITS LAGOON

A. Marani and E. Calogero (University of Venice, Dorsoduro 2137 - I-30123 Venezia, Italy)
B. Eiselt (Istituto Veneto di SS.LL.AA., Campo S. Stefano 2945 - I30124 Venezia, I taly)

The unique characteristics of Venice and its lagoon (northern Italy) represent a special challenge for environmental management. This highly developed territory is an ar ea with high risk of natural and non-natural hazards: flooding (high tides), water and atmospheric pollution, subsidence and even the risks involved with projects aime d at reducing environmental hazards. Environmental management requires a deep knowled ge of the territory and many researches have indeed been carried out in the area du ring the last years. "Sistema Lagunare Veneziano" (SLV) is one of them. An important as pect of this project is an emphasis on the availability of existing information and scie ntific data and the creation of a database accessible by Internet. The database has been str uctured into three different modules: a data section, a bibliographic section and a mode ling section. The data section contains most of the results of the studies carried ou t within SVL project. The bibliographic section contains references to papers and reports funded by the project. The modeling section contains the codes of models produced for the project and their most relevant results. The site address is: http://www.ivsla.unive.it.

RISK ASSESSMENT IN BARCELONA, SPAIN, USING GIS

U. Mena[(1)], A. Barbat[(1)], J. A. Canas[(1)], L. G. Pujades[(1)]

[(1)] Polytechnical University of Catalonia

Previous research on risk in a central area of Barcelona, called the Eixample, have showed middle and high building vulnerability indices, in agreement with the actual state and the design details of the analyzed buildings. The seismic scenarios simulated for this area showed an unadequate seismic performance for reinforced concrete buildings. These structures presented a high risk, especially the flat-slab buildings. This fact motivated to proceed with the seismic risk studies in other areas of the city, in order to propose seismic risk mitigation measures.
The aim of this work is to apply the italian vulnerability index method in the evaluation of the structural seismic quality of buildings for these new areas of Barcelona. This evaluation metodology is adequate in vulnerability studies for large urbans zones. Furthermore, the vulnerability functions obtained for non-reinforced masonry and reinforced concrete buildings existing in Barcelona will be applied to asses the seismic risk for different levels of macroseismic intensity.
Finally, the results, which are basically vulnerability indices, will be implemented in a Geographical Information Systems to develop probable damage scenarios.

PREDICTION OF SOIL EROSION RISK USING GIS PROCEDURES

G. Mendicino and P. Versace (Dipartimento di Difesa del Suolo, Università della Calabria, C.da S. Antonello, 87040 Montalto Uffugo (CS), Italy)

Land degradation by water erosion represents one of the major issues in the field of the environmental planning.
Soil erosion and sediment transport are spatially distributed processes, and their evaluation can be easily realized by means of the use of Geographic Information Systems.
The greater availability of digital and geo-lithological data managed and stored inside GIS has implied the development of techniques and procedures aimed to the definition of the spatial prediction of erosion and deposition rates across a catchment.
In this paper, by means of the data directly measured on an experimental basin in Southern Italy, an analysis on different GIS-based methodologies has been done with the aim of determining the spatial erosion risk assessment of the examined basin.
Finally, the performances of the adopted procedures have been evaluated comparing these results with those directly obtained on the experimental basin.

USE OF LANDSLIDE ACTIVITY MAPS FOR THE EVALUATION OF LANDSLIDE HAZARD: THREE CASE STUDIES FROM SOUTHERN ITALY

M. Parise & J. Wasowski (Cnr-Cerist, via Orabona 4, 70125 Bari, Italy)

This paper focuses on the application of landslide activity maps for evaluating the mass movement hazard in selected areas of the Southern Apennines: Bisaccia, Calitri and Buoninventre. The three landslide areas show relatively rapid morphological evolution, whose main evidences can be easily identified from air-photo examination. The availability of multi-year aerial photo coverage (from 1954 to 1995) helped to assess the morphological changes which occurred in the last 40 years. Hummocky topography, fresh scarps, cracks, abrupt changes in the drainage network, slide ponds are among the main features which were used to recognize and delimit the zones affected by active mass movements and associated intensive erosion. The interpretation of each time series of aerial photos generated several large-scale (1:10,000) maps, which emphasize differences in spatial distribution of landslide phenomena and in their state of activity. In addition, attention was paid to increased urbanization and development, and to any significant land use changes in the area. The most recent (last two years) temporal and spatial changes were assessed also through frequent field controls. These data were integrated with historical accounts concerning slope instability episodes in order to provide a more complete overview of the landslide evolution. This relatively inexpensive method represents a valuable tool for estimating the long- and short-term mass movement hazard. The comparative study of landslide areas shows that in some cases remedial works can significantly reduce the state of activity of slope movements and their distribution. It should be stressed, however, that the examination of causative conditions and processes is essential for improving the reliability of the predictions based on landslide activity maps.

REDACTION OF A CIVIL PROTECTION PLAN FOR SEA-RELATED HAZARDS

E. Pugliese Carratelli (Dipartimento di Ingegneria Civile, Fisciano I84084, Italy)
E. Sansone (Istituto di Meteorologia ed Oceanografia, IUN, I80133, Naples)
G Spulsi (Istituto di Meteorologia ed Oceanografia, IUN, I80133, Naples)

A prediction and warning system against sea-related hazards is being developed on behalf of the Local Authority of the Salerno Province (Southern Italy) by CUGRI, a research centre which specialises on hazard prevention. The system - which is in turn part of a more general civil protection plan - will be organised around four subsystems
a) Weather alert b).Offshore sea state forecast c) Wave transformation towards the coast d) Run-up modelling
While subsystems a and b e will be largely based on Italian and/or European Meteorological services supplied under contract, and partly shared with other se ctors of the Civil Protection and other coastal regions, subsystem c and d are very specific to the area considered. Wave shoaling and run-up will be evaluated with both experimental formulas and specialised software. The paper presents a general outline of the whole sea hazard plan and shows results of sample calculations of run-up and potential damage assessment in several coastal sites, carried out by making use of sea state data derived from recorded and synthesised data of previous storms and from extreme value analyses of the sea climate in the area.

EVALUATION OF NATURAL HAZARDS FOR THE DISASTER MANAGEMENT SYSTEM BY USING GIS AND REMOTE SENSING - AN ANALYSIS OF THE GREAT HANSHIN EARTHQUAKE -

Bambang Rudyanto, Yujiro Ogawa, Hitoshi Taniguchi, Eiichi Itoigawa

The Great Hanshin Earthquake with 7.2 on the Richer Scale abruptly occurred breaking the silence of the early morning of 17 January 1995. More than 5,000 people living in Kobe were crushed to death. Considering that this huge disaster struck Japan, which considers itself to be a "Developed Country", reminds us that the need for disaster management is not only in developing countries but also in every place in the world. At the moment, disaster management system can not be separated without using techniques and tools for mapping, referred to as Geographic Information System (GIS) and Remote Sensing. The analysis revealed that nearly 200,000 buildings had been damaged by the direct effect of the earthquake. From this results, we overlaid the digital map and SPOT satellite images in such a way that at the end, the images before and after damages could be compared easily. By using this kind of GIS and Remote Sensing techniques, natural hazards in wide areas can be observed quickly and the method can be standardized. Also data stored can be retrieved at anytime because of the advantage of using computers.

NATURAL RISK FACTORS IN INDIUSTRIAL AREAS: STUDY CASE ANALYSIS AND DESCRIPTION

F. Silvestri, G. Di Filippo (ISPESL - Productive Settlements and Enviromnental Department, Via Urbana 167, 00184 Rome, Italy)

E. Cardarelli (Rescareli Università La Sapienza - Department of Hydraulics, Transports and Roads, Geophysical Area - Rome, Italy)

Natural risks may interact witl the risks coming from the industrial plants, especially from the high risk ones giving rise to a negative synergism. In Italy, as in other countries, the topical interest for this problem is proved by the increasing number of risk situations linked to a wrong approach to their analysis. In oder to get a complete evaluation of the interactions between industrial settlements and environment, it's necessary to consider their double connection: the effects both of a natural event on the plant and of the plant itself on the surrounding environment. Therefore, we need infomiation about territorial features, like hydrogeological and geomorphologic factors, and suitable safety measures, which are nowadays not available for specific situations. Finally, we suggest a standardization of evaluation procedures and risk mapping, aimed, in the preventive phase, at the localization and planning of industrial plants and, in the following phase, at the reclaiming, recovery and reinstatement of the environment. The paper examines the causes and the mechanism of the environmental risk, in particular hydrogeological factors, and its evaluation in one industrial area and illustrates the methodology and the results of its application.

THE VAŇOV LANDSLIDE

Josef Stemberk (Institute of Rock Structure and Mechanics, Czech Academy of Sciences, V Holešovičkách 41, CZ-18209 Prague 8, Czech Republic
Jan Novotný, K+K PRUZKUM, Co., Ltd., Novákových 6, CZ-18000 Prague 8, Czech Republic

In 1995 a considerable increase of the slope movements in the Bohemian Massif was registered. The Vaňov Landslide, a huge landslide activated in 1995, is situated on the left bank of the Labe River. The sliding area is about 300 m long, denivelated by 160 m. Movements originated in places where older landslides had been reported. Local geological conditions appear to influence the dip of the slope and the origin of individual movements here. The upper part of the slope is built by 220 m thick complex of the Tertiary volcanic rocks overlying the Cretaceous sediments outcropping in the lower part of the slope. A landslide scarp of the active flow-type slide evoluated just under separated basalt blocks. The flow slide located in a place of frequent old sliding, was strongly accelerated in May and June 1995 up to a maximum rate 6 cm per day. Thid happened after the long-term precipitation balance culmination. This increased amount of the rainfall can be blamed for slide reactivating as the main factor under conditions of favourable geological predisposition and its state of limit balance.

NATURAL HAZARDS AS EXAMPLES OF SELF-ORGANIZED CRITICALITY

D.L. Turcotte, B.D. Malamud, and G. Morein (Dept. Geol. Sci., Snee Hall, Cornell Univ., Ithaca, NY 14853 USA)

These simple classes of models have been proposed that exhibit "self-organized criticality". These are "sand-pile" models, slider-block models, and forest-fire models. Although these models are extremely simple, they appear to be representative of the behavior of common natural hazards. In the case of the "sand-pile" models the application is to landslides. Both the models and several landslide data sets satisfy power-law (fractal) statistics to a good approximation. Similarly the behavior of slider-block models can be associated with earthquakes and the behavior of forest-fire models with forest and wild fires. In the models the smaller events "prepare" the systems so that they "self-organize" and exhibit fractal statistics. The frequency of occurrence of smaller events can be extrapolated to estimate the frequency of occurrence of the larger events. Despite all the problems of weather and climate, the great varieties of combustible materials, and attempts to extinguish wild fires, the frequency-magnitude statistics of wild fires are fractal to a good approximation under a wide variety of circumstances. It has long been recognized that earthquakes obey fractal frequency-magnitude statistics. The fractal dimension is simply twice the b-value. The a-value is a measure of the intensity of the regional seismicity. It is shown for southern California that the a-value is the same for each year over a fifteen year period when aftershock sequences are removed. World-wide maps of a-value have been prepared and can be used to estimate the global seismic hazard.

FORMALIZING EXPERT OPINION IN LANDSLIDE HAZARD ZONATION

C.J. van Westen, International Institute for Aerospace Surveys and Earth Sciences (ITC), Enschede, The Netherlands. F. Mantovani, University of Ferrara, Italy, and A.C. Seijmonsbergen, University of Amsterdam, The Netherlands

The aim of this project is to evaluate the decision rules used by expert geomorphologists in the direct mapping of landslide hazard zones. Originally, before the widespread use of geographic information systems, landslide hazard mapping was done by means of direct mapping. The decision criteria used by the geomorphologists were not made clear to the user, and were often not formalized. During the last decade landslide hazard mapping is mostly done by data integration techniques in a GIS (using either bivariate or multivariate statistical techniques). Since most of these techniques are data-driven, the expert knowledge of the geomorphologist is not used sufficiently, often leading to incorrect results. This project aims in utilizing the expert knowledge on causal factors for landslides, within a GIS environment. This means that the geomorphologist who is preparing the hazard map should make clear why he considers a certain unit to be hazardous. One of the aims of the project is to develop a hazard database from which a user (for example a municipal planning authority) can consult these criteria why a certain unit has been classified as high, moderate or low hazard. He can consult this information together with other relevant information (landcover, infrastructure and cadastral information). A method is presented using ILWIS 2.0 in which this consultation procedure becomes very simple. A very detailed database was constructed within the new ILWIS 2.0 for Windows at a scale of 1:5.000 containing the following types of information: Topographical data, Infrastructural data, Landcover map, Geological map, Geomorphological maps, and three direct hazard maps made by three different groups. The direct hazard map was prepared and digitized, and was linked with the geomorphological information, so that for each of the approximately 1800 hazard polygons which were identified, information can be obtained on the hazard degree (high, medium and low), the hazard type (including rockfall, landslides, flowslides, flows, erosion, and flooding) and the decision criteria for defining the hazard.

NH3 Seismic hazard assessment in active tectonic regions

Convener: Avouac, J.-P.
Co-Convener: Console, R.

SEISMOTECTONIC ENVIRONMENT FOR YEMEN

Sahil Alsinawi,Faculty of Science,Sana'a University.Maeen P.O.Box 13022 Sana'a, Yemen
Ahmed Alaydrus,Faculty of Science,Sana'a University .

The seismicity of Yemen is closely related to the regional Basement tectonics,volcanicity and associasted thermomineral springs.The expanding Red sea due to the Arabian Plate northwesterly rotation during the Tertiary and Quaternary, are the major controlling factors .
The study area is defined by latitudes (40-55)degrees north and longitudes (10-20) degrees east. Recent events include the Sadah earthquake (M≤6) of 1941 and the Dhamar earthquake (M≥6) of 1982. Recent seismicity includes Al-Udayn earthquake sequence (M≤4.6) of 1991,Haidan earthquake sequence (M≤4) of 1993 and Hais earthquake (M=4) of 1993. The recent seismicity for the period (1900-1994) was compiled , and a catalogue of (750) events was analysed.The total recording period was seen to fall into four time intervals.The total seismicity rate of 7.9 event/year was found .The dominant magnitude range lies between (2<mb<6). Focal depth values gave focal depths of 10 kms for 40% 0f the events and 33 kms for 27% of the events These two focal depths probably mark lithologic,tectonic and volcanic chamber zones. The Gutenberg-Richter Recurrence relationship was investigated for the total recording period to give; Log(N) =2.5−1.1 mb.Two isointensity maps were plotted , for the epicentral distances of 100 and 300 kms . A seismotectonic map was prepared and two seismogenic zones were defined.namely the Continental Yemen and the Oceanic Yemen zones.The first seismogenic zone is further subdivided into the Yemen Plateau and the Hadramout siesmogenic subzones. The peak ground acceleration maps for the area were constructed for two attenuation radii of 100 and 300 kms.

SMALL EARTHQUAKES, LARGE SCALE TECTONIC PROCESSES AND THE DIFFERENCE IN EARTHQUAKE SCALING LAWS BETWEEN CREEPING AND NON-CREEPING FAULTS

Falk Amelung IPG de Strasbourg, 5 Rue Rene Descartes, Strasbourg, France.
Geoffrey King IPG de Paris, 4 place Jussieu, 75252, Paris, Cedex 05 France.

We examine the strain released by small earthquakes and compare it with geological, geodetic and plate tectonic measurements of deformation. Using a very large data set from the San Francisco Bay area we show that the strain due to small earthquakes is on a large scale, closely related to the plate motion and, on a smaller scale, to specific geological features. Moment summation of small earthquakes offers a new tool to understand tectonic processes. By examining how the strain due to earthquakes at one scale relates to the strain by earthquakes at another scalewe show that the strain orientations are independentof earthquake size, indicating the self-similarity of earthquake strain. The self-similarity breaks down for the largest events suggesting that the time interval has not been largeenough to sample a complete set of events. In particular, the Bay area lacks a large event of the type that is expected to occur on the Hayward fault. We also find that the dependence of the summed moment release on the fault dimension differs between non-creeping faults and creeping faults or volcanic regions. This can be attributedto different earthquake scaling laws. The number N of events with fault length L scales for non-creeping faults as N(L)~L-2 and for creeping faults as N(L)~L-3. In Central California the summed moment-fault length distributions indicate that the San Gregorio fault is non-creeping and will be the source of a major earthquake.

ACTIVE FAULTING, SLIP RATES, DISTRIBUTED VS LOCALIZED DEFORMATION IN THE AEGEAN: IMPLICATIONS FOR SEISMIC HAZARD ASSESSMENT

R. Armijo, B. Meyer, and G. King (IPGP, 4, Place Jussieu, 75252 Paris, France)

Recent destructive earthquakes in the world (Northridge, California, 1994; Kobe, Japan, 1995; Grevena, Greece, 1995) remind us how crucial is for seismic hazard assessment to incorporate information about faulting. All these earthquakes were "unexpected" because no evidence of activity was detected in the seismicity (instrumental and historical) or with the geodetic surveys. The longer-term imprint of fault activity, however, was evident in the morphology. For some of the major fault systems in the Aegean region the morphologic study of active faulting provides now reliable estimates of slip rates and of recurrence times of large earthquakes. Slip rates range from about 1 mm/yr or less in most of the normal faults in the region, to about 1 cm/yr localized on some particularly fast systems as the Corinth Rift. The fast faulting in Corinth appears to result from its present location in the inhomogeneous stress field (process zone) of the southwestward propagating tip of the North Anatolian Fault. We use these observations to derive a mechanical model for the evolution of the Aegean region. The model incorporates more plausible strain rates than hitherto inferred from directly summed seismic moment tensors. It is compatible with tectonic observations, as well as with the seismicity, the paleomagnetic rotations and the displacement field now observed with GPS and SLR. The inference of localized deformation has strong impact on seismic hazard assessment over the region.

RECOGNITION OF FORESHOCK-MANIOCA SERIES FOR EARTHQUAKE PREDICTION: APPLICATION TO SPANISH SEISMICITY

Simone Ballatore Instituo Geográfico Nacional, Madrid, Spain
Julio Mezcua Instituto Geográfico Nacional, Madrid, Spain

Our study focuses on foreshocks of earthquake sequences recorded by the Spanish Seismological Network from 1975 to 1996. Foreshocks were defined as events of magnitude M_j exceeding a given threshold magnitude, that follow a period of quiescence and come before a mainshock occuring within a given time-distance range. Adopting the Akaike information criterion (dAIC) to assess the optimal set of space-time parameters used to define foreshocks, we carried an investigation over the whole Spanish territory to identify the zones where foreshocks-mainshocks series are likely to occur. By means of the algorithm for the objective definition of foreshocks, we have identified a region in South Spain (Beticas-Alboran), and another in South-West (Algeria), where there is a significant tendency of moderate shocks to be followed by mainshocks in a short temporal-spatial range. Our analysis shows that in these zones, a total of 768 and 865 events respectively, the rate of earthquakes of magnitude larger than or equal to 4.0 are preceded by at least one foreshoch of magnitude larger than or equal to 3.0 within 35 km and 6 days for the first region, and 42 km amd 5 days for the second one, is respectively 45.7% and 53.6%, and in same time range the rate of M≥3.0 earthquakes followed by a M≥4.0 is 3.9% and 5.2%. We ran the same algorithm on the data selected in another larger zone (Golfo de Cadiz) including 454 events of M≥3.0. Here the success rate is about 3.1% and comes from 5 successes out of 41 mainshocks and 95 potential foreshocks. By applying our algorithm over a dense grid of spatial coordinates we obtain maps of success rates for two different values of magnitude threshold for mainshocks, so understanding that most of the seismic activity in the Spanish territory is characterized by single shocks.

SURFACE FAULTING IN THE ROER GRABEN: IMPLICATIONS FOR THE ASSESSMENT OF SEISMIC HAZARD

T.Camelbeeck, K.Vanneste and M.Brondeel (Royal Observatory of Belgium, av.Circulaire 3, B-1180 Bruxelles)
M.Meghraoui (CNR, Centro di Studio per La Geologia Tecnica, via Eudossiana 18, 00184 Roma)

Paleoseismic investigations along a10 km fault scarp in the Belgian part of the Roer Graben, indicate the occurrence of at least three paleoearthquakes during the last 14,000 years. ^{14}C dating indicate that the last earthquake along the fault scarp occurred between 430 AD and 940 AD and produced an average coseismic vertical displacement of 0.6 m, from which an M_W magnitude of at least 6.4 may be estimated. This value is a minimum, because a longer rupture length can also be taken in consideration for each paleoearthquake considering that the fault scarp which separates the Campine Plateau from the Roer Graben disappears to the southeast where it crosses the Maas valley, but becomes visible again in the Netherlands reaching a total length of 35 km. The duration of the seismic cycle is of the order of 3,500-5000 years and the recent vertical deformation rate is 0.2-0.3 mm/y. On the basis of historical and instrumental seismicity, the Gutenberg-Richter relation suggest an average return period of more or less 30,000 years for an earthquake with magnitude M_W=6.4 along a fault fragment of 15 km along the Roer Graben. This value, between six and ten times the return period suggested by the Bree scarp study, questions the extrapolation of the regional frequency-moment statistics to estimate the potential of large earthquake in the Roer Graben.

LOCALISATION OF ACTIVE FAULTS IN A MODERATE SEISMIC REGION: EVIDENCES FROM EPICENTRES DISTRIBUTION, GEOMORPHOLOGY, LEVELLING REITERATION AND GAS EMANATION DATA (FRENCH WESTERN PYRENEES)

P. Courjault-Radé, J.P. Toutain, J. Darrozes (UMR 5563 CNRS 38, rue des 36-Ponts, 31400,Toulouse, France)
J.C. Baudron (BRGM, 40060 Orléan Cedex, France)

The Bearn ranges is one of the most seismically active areas in France. A shallow M=5.1 earthquake occurred on February 29, 1980 near Arudy, followed by a large number of M≥ 1,5 aftershocks distributed in a 15 km^2 area. This large set of epicentres has been analysed using a new software allowing detection of multi-scale linear structures (NOAWC software - Darrozes and al., submitted). The linear structures have been cross-enriched with information of different origins: glacial geomorphological markers, comparison of levelling data and gas emanations profiles (He, Ra , CO_2). Such a procedure yields an accurate localisation of the active faults, and gives clues for establishing a risk estimation map of the area. On the basis of this map, surveillance by levelling reiterations and radon continuous monitoring of the main potential rupture planes, are now performed.

ATTENUATION OF CODA WAVES IN BELGIUM : SPATIAL VARIATION AND TWO-DIMENSIO NAL STRUCTURE

A.El Bouch (Royal Observatory of Belgium, Av.circulaire 3, 1180 Brussels, Belgium)

Coda wave quality factor, Q_c, has been determined in Belgium and surrounding regions. We analyzed the decay rate of coda waves amplitude on narrow band-pass-filtered seismograms of local earthquakes that occurred during the period 1985-1992 and recorded by the Belgian seismic network. Apparent attenuation was estimated by implementing two techniques derived from the S-S single-scattering model in the time domain and the frequency domain. The number earthquakes selected (86) cover short epicentral distances (1-65 km), focal depths up to 23 km and magnitude $0.5 < M_L < 4$.
We investigated the dependance of Q_c on frequency using over a wide frequency by using five narrow frequency bands centered at 1.5, 3, 6, 12, and 24 Hz . Q_c depends on frequency, f in Hz, according to a power law, $Q_c = Q_o f^n$. The exponential value of the Q_c frequency dependance varying between 0.7 and 1.46. The average Q_c variation ranges from 23 to 165.8 at 1.5 Hz and from 1035 to 3860 at 24.0 Hz.
The results show spatial Q_c variations, in agreement with the lateral heterogeneities that characterize the area.
Crustal 2-D Q_c structure is presented and suggest relationships with macroseismic data of some recent earthquakes. These results may be helpful for seismic hazard assessment and for earthquake engineering purposes.

LIQUEFACTION AND SOFT-SEDIMENT DEFORMATION STRUCTURES INDUCED BY EARTHQUAKE

J.O. Caselles, J.A. Canas, L. Pujades, V. Pérez, J. Clapés, ETSICCP, U. P. de Cataluña, Barcelona, Spain
P. Alfaro, Escuela Politécnica Superior, Univ. de Jaén, Spain
M. Moretti, Univ. degli Studi di Bari, Italy.

A steel box with 90x40x45 cm dimensions mounted on a three-axis shaking table has been used to simulate liquefaction phenomena occurring in water saturated sands during earthquake shakings. 14 experiments were performed anf five of them were monitores by introducing six pore pressuremeters and five accelerometers in the soil samples; two additional accelerometers were intaled on the steel box. In this way we were able to observe the lab experiments and we present some of the produced liquefaction and soft-sediments deformation structures: fluid scape, sand volcanoes, water filled voids, pillars and dishes, load casts and re-sedimentation processes. Some of the causes producing these phenomena are also discussed.

A MULTIDISCIPLINARY EXPERIMENT TO CHARACTERIZE AN ACTIVE FAULT SYSTEM IN MODERATE SEISMIC ACTIVITY AREA: THE EXAMPLE OF THE DURANCE FAULT (SOUTH EASTERN FRANCE)

M. Cushing, Ph Volant (IPSN, BP6 92265 Fontenay aux Roses, France)
Bellier O., Sebrier M., Barroux E. (URA CNRS, Bat 509, F-91 405 Orsay Cedex)
B. Greliet, Ph. Combes (Geoter, 3, rue Jean Monnet, 34830 Clapiers)
Th. Rosique (CAGEP, URA-CNRS 903, UFR Géographie, 13621 Aix-en Provence)

The seismic potentiality of faults is difficult to assess in areas with low or moderate seismic activity. A comprehensive study has been developed in South Eastern France, in order to assess seismogenic behaviour of a low slip-rate fault zone: the middle Durance fault area. The aim of this multidisciplinary and detailed study is to obtain a good understanding of this complex fault system and of its potentiality in term of seismic hazard assessment. A few years study demonstrates that a multidisciplinary approach is necessary to characterize such a complex fault system.
The Durance fault zone is a 60 km long major oblique-slip fault which affects probably the whole thickness of the crust in the alpine foreland. This fault system is considered as an active fault. Paleoseismic studies showed that at least one paleoearthquake produced a vertical displacement of about one meter between 26 ky and 9 ky. Moreover, this fault exhibits macroseismic historical earthquakes with magnitudes (M_L) between 5.0 and 5.5 and with a known return period of 100 years since the XVIth century. This fault zone is also characterized by a regular microseismic activity. A large spectra of methodologies has been carried out (remote sensing and DEM analysis, ground mapping, archeological and cavern investigations, paleoseismological trenches, reinterpretation of seismic profiles, installation of a permanent local seismological network, geodetical measurements). The global interpretation of all the results using these different methods provides a better comprehension of the 3D geometry, the kinematic and the seismic potentiality of this complex fault zone.

SPECTRA OF REACTION AT THE RECORDS OF STRONG EARTHQUAKES OF KYRGYZSTAN

A.G.Frolova (Institute of seismology, NAS, Asanbai, 52/1, 720060, Bishkek, Kyrgyzstan)

Spectra of reaction were calculated for strong earthquakes in term of displacements, velocities and accelerations. Three parameters were used for analysis of spectra diversity - maximum level, resonance period and logarithmic width of spectrum on three level from maximum. Characteristics of distribution these values have been estimated. There were received the average normalized spectra of reaction, that are characteristic for strong earthquakes of Kyrgyzstan.

DEFORMATION IN THE VICINITY OF THE SEISMOGENE STRUCTURES

L.A.Khamidov, D.B.Kramarovsky (Institute of Seismology, Uzbekistan Academy of Scienecs)

Problems on construction of the computational models of tectonic flexures with increased possibility of stress concentration are solved with the use of boundary element models. Forms of deformations for different types of stress concentrators are analysed. Results obtained allow to estimate the corresponding changes of the displacement components on the free surface. The comparative analysis of the theoretical models and the tool-making results is made with the imitation of the stress concentrator zones of the earthquake areas with M>5 (M is the source magnitude) in the zones of seismogene flexures and faults in the east part of Central Asia. This analysis allow to conclude that the internal stress concentrators with friction in contacts are more acceptable and are in a good agreement with tool-making data.

THE SEISMOTECTONIC ZONES OF CENTRAL EUROPE

V.I.Khomenko (Inst. of Geophysics, Nat Ac Sci Ukr, Kyiv-142, Ukraine 252142)

A system analysis of geophysical and geological data has been made which was preceded by compiling some composite maps (of M-relief, gravity and geomagnetic fields, RVMEC, erthquake epicentres and Wiese vectors position). As a result a scheme of deep structure of the region was constructed, whose main elements are ovoid - circular structures - nuclears, reflecting the ancient convection - advection hearths in crust and upper mantle. Consideration of the whole materials enabled us to separate three systems of seismoactive zones of the following orientations: 1) NW-SE (Bialogard-Lviv-Odessa, Szczecin-Przemysl-Jassy-Krylovskaya, Wroclaw-Zakopane-Halmeu-Bucharest, Sudety-Uzhgorod-North Dobruja, Leipzig-Budapest-Beyleshty); 2) SW-NE (Lublana-Vienna-West Carpathian, Subotitsa-Baia Mare-Cherniwtsi, Vrancea Mts zone); 3) W-E (zone Alpine-Budapest). As a rule, seismo-tectonic zones are active in internuclear space and on the peripheries of the nuclears. These zones are not only marked whithin the surroundings of the ancient platform but also on its slope (Bialogard-Lviv-Odessa zone). Potential seismic activity may be assumed within the ancient platform proper at the NE-continuation of the zone Vienna-Zakopane-Lviv - Rogatyn-Chornobyl paleorift zone.

SISMOTECTONICS OF WADI ARABA FAULT (JORDAN)

Y. Klinger (E.O.P.G., 5 r. René Descartes, F-67084 Strasbourg, France)
J.P. Avouac (L.D.G., C.E.A., F-91680 Bruyeres le Chatel, France)
N. Abou Karaki (Dept. Geology, Univ. of Jordan, Amman, Jordan)

The Wadi Araba, between the Gulf of Aqaba and the Dead Sea, is known as a transform fault system, with a cumulative displacement of 107km since the last 15 millions years. The most active segments of the transform at the present day are the Dead Sea basin and the Gulf of Aqaba where a magnitude 7.2 event occurred on November 22, 1995. However, no seismic activity was recorded in the Wadi Araba, excepted few microearthquakes. Even during historical times, the rate of seismicity seems to be very low from the information we have until now. The Wadi Araba is a desert area and so tectonics features are well preserved for a long time. We mapped the Wadi Araba segment between latitude 30°N and 31°. In the north of the studied zone, we can find evidences for left-lateral movement at large scale. Two alluvial fans, probably of Pleistocene age, are offset by the fault with their apices lying 500m away from feeding rivers. This amount of displacement is compatible with the velocity derived from global tectonics models. At smaller scale we can find many evidences for the left-lateral movement We focused more carefully on the offsets of streams and terrace risers crossing the fault. Preliminary results show that, at all place we visited, the smallest incremental displacements we can measured are around a value of 1.5 meter. That could be associated with a characteristic earthquake of magnitude 7 as indicated from historical seismicity. Bigger displacement are also observed and probably correspond to several events.

Quantitative morphological method for assessment of geological environment stability in urban seismic active areas

Kononov E.E.(StateTechnical University,664074 Lermontov st.,83, Irkutsk, Russia)

The quantitative morphology is fundamental important for assessment of consequences by earthquake influences. That part of geomorphology is a distinctive method investigating numeral characteristics of landscapes. The maps of the river valley orders, of the erosional dismemberment, of the steep slopes are more informative for the assessment of the geological environment stability from our standpoint. Fluvial streams are the best sensitive index of tectonic condition hanges.The maps of the river valley orders provides a way of areas differentiate on various movements blocks with confidence. The erosional dismemberment define the geological environment stability at external influences essentially. The more vulnerability of the geological environment, the higher of the erosional dismemberment amplitude as consequences of the seismic activity.The steep slopes is the determination parameter for initiation and development lot of the geological processes as well as gravitation collapses, landslides, landslips, ets. Anthropology genesis changes of the steep slopes can provoke exogenous geological processes unknown early in this area. The map of the steep slopes let us make a forecast of the geody-namic process development as a result of the earthquake activity. Geomorpholo-gical evidence are only one part of complex analysis of the geological environment stability it is based on an integral index including a great deal of another geological parameters and technical origin loads data. That method of approach to the assessment of the geological environment stability makes possible to create new system data handling and has given impetus to rethink our old views.

SEISMICITY AND DISTRIBUTION OF SEISMIC ENERGY RELEASED IN ALBANIA

B.Muço (Seismological Institute, Tirana, Albania)

The seismicity of Albania is high and intensive, especially microseismicity. Located in a very important part of the interaction zone between the Adria and Eurasian lithospheric plate, this country has some of the highest seismic activity in the Balkans. Albanian territory is dissected by numerous active faults and the earthquake depths indicate that dynamic processes happen mostly in the crust.
Some different features of seismicity are evidenced for the inner and internal part of the country. Analysing the historical and instrumental seismicity, in this approach it is studied the distribution of seismic energy released in Albania during the period 1976-1994. The mapping of seismic energy and cumulative magnitude for about 20 years could help for hazard assessment of the country.

ANOMALY OF GEOMAGNETIC FIELD VARIATIONS (GFV) IN ACTIVE TECTONIC REGIONS - A SOURCE OF SEISMIC HAZARDS (SH)

Naumov A.P.,
D.I.Mendeleyev Institute for Metrology

The paper presents some results of investigations of the GFV in the Crimea, as well as possibitities for short-term forecasting about SH. The cesium fast-acting magnetometers registered GFV during three summer seasons. The pulse anomaly of GFV has been found (short-period signals of 0.1 - 20 s. at an amplitude of up to 50 nT), which procedes weak earthquakes. These signals were registered by sinchronized magnetometers located at a distance. That provides to determine exactly the coordinates of source anomaly.

COMPARISON OF GEOLOGICAL, MORPHOLOGICAL AND SEISMOLOGICAL INFORMATIONS IN A ZONE OF MODERATE DEFORMATION: THE EXAMPLE OF SOUTH-EASTERN FRANCE.

M. Nicolas, A. Schlupp, S. Bottard and J.P. Avouac (CEA / LDG / TRS BP 12 91680 Bruyères le Chatel, France)

The characteristics of active tectonics in south-eastern France can be achieved from either geological and morphological information or from seismological data. Some major faults such as the Nimes strike-slip fault or the Durance strike-slip fault appears to show off from both their seismological and morphological expression. Other structures, inferred to be active from their morphological signature, are not known to have produced any large earthquakes over the historical period. The seismic hazard associated with such structures can however be roughly assessed on the basis of simple rules. One rule is that the various active faults must make a consistent kinematic pattern. Another rule is that, regionaly, the seismological catalogue must follow the Gutenberg-Richter law. Finally, one may also assume that the return period of a characteristic earthquake, at a given point in a fault, must account for a constant fraction of the long-term slip rate. Such rules can provide the basis for a probabilistic approach of seismic hazard assessment, in a way that account for the complementarity of the seismological and morphological approaches.

FAULT GEOMETRY AND KINEMATICS OF THE SHANXI RIFT SYSTEM (CHINA). YIANQING-HUALAI ACTIVE FAULTS CASE STUDY

S.B. Pavlides (Dept. of Geology, Aristotle University of Thessaloniki, 54006 Greece, E-mail: Pavlides@geo.auth.gr)

Huailai and Yanqing active normal faults are parallel structures 50 to 30 km long respectively. They lie at the northern edge of the Pliocene-Quaternary Shanxi Rift system. This fault system is a fundamental structure in Northern China with a total length of 1000 km and a maximum width of 400 km oriented NNE-SSW and it is divided in many segments and strands. The northern edge termination, that is Huailai and Yanqing faults, are typical extensional major structures, where morphotectonic features, such as triangular facets, stream deviation, active fault scarps has been recognized and dip-slip or oblique-slip normal components of slip-vectors permitted to quantitative analyse the kinematics of faults. The crustal late Quaternary deformation (NW-SE extension) is localized mainly along the marginal fault of semi-graben basins. The initiation of high-angle normal faults strongly influenced by the presence of lithological heterogeneities and mainly by the pre-existing inherited discontinuities within the basement. In the case of flat and ramp fault geometry interpretation extensional deformation is controlled by deep low-angle heterogenetics and detachment surfaces and second order high-angle normal faults in the uppermost crust. The high-angle main normal faults can be better explain the tilted blocks, asymmetrical basins, multisemgented, zigzag oriented faults, and the influence of pre-existing basement fabric, e.g. platform type orthogonal joints and faults.

HOLOCENE KINEMATICS OF THE FUCINO BASIN (CENTRAL APENNINES, ITALY)

L. Piccardi*, Y. Gaudemer**, P. Tapponnier**, M. Boccaletti***
* C.N.R., Centro di Studio di Geologia dell'Appennino e Catene Perimediterranee - Firenze.
** Institut de Physique du Globe de Paris, Laboratoire de Tectonique - Paris.
*** Universita degli Studi di Firenze, Dipartimento di Scienze della Terra - Firenze.

The Fucino Basin is a flat depression in the central Apennines. It is bounded by active faults, mostly normal but showing at places a slight strike-slip component of motion. Several of these faults were activated during the M =3D 6.9 earthquake of 1915. In order to better understand the kinematics of this region, we have carried out a detailed structural and morphological analysis of fault scarps around the Fucino Basin. While the Magnola and the Tre Monti faults are very active, on the northern side of the basin, the faulting pattern is not as clear as on the eastern side of the basin. There, the Serrone, Parasano and Ventrino faults are arranged in a right-stepping fashion, suggesting left-lateral shear in a direction parallel to the system. The right-lateral component of motion indicated by slickensides on all the three faults, and the offset of small streams across the Ventrino fault, suggests that the blocks bounded by these faults rotate counterclockwise, in a manner typical of "bookshelf" faulting. Given the values of slip-rate derived from the offset of post-glacial morphology, 0.5 to 1 mm/yr, the rotation rate in the east of the Fucino area is of 2-4 deg/Myr.

NEW APPROACH TO EVALUATION OF EXTREME PARAMETERS AND LOSSES FROM EARTHQUAKES

V.F.Pisarenko (Int. Inst. of Earthquake Predict. Theory and Math. Geophysics RAS, Varshavskoye sh., 79-2, 113556, Moscow, Russia).
M.V. Rodkin (Geophysical Center RAS, Molodezhnaya 3, 117296 Moscow, Russia, rodkin@wdcb.rssi.ru)

Empirical distributions of energy and seismic moments of earthquakes and of the losses caused by them have a power-law character. When the power-law distributions have a "heavy tail" (that appears to be a wide-spread case), order statistics are to be used for loss evaluation, because the common-used time averaged values become highly unstable and thus useless. If a "heavy tail" occurs the medians of losses increase in a non-linear manner with time. This increase occurs until the used time interval becomes equal to recurrence time of the "strongest" possible disaster. The change from the non-linear law of increase of medians to the linear one can be determined from empirical data and thus the "size" and the recurrence time of the "strongest" disaster can be evaluated. We had used this approach to evaluate the extreme characteristics both of physical parameters of earthquakes and of losses. Time evolution of numbers of earthquakes that had caused lower losses is discussed also.

NEW TECHNIQUES FOR SEISMIC HAZARD ASSESSMENT OF ACTIVE TECTONIC REGIONS IN SOUTH EUROPE

G.I.Reisner (Institute of Seismology UIPE RAS, 123810, Bolshaya Gruzinskaya, 10, Moscow, Russia)
L.I.Ioganson (Institute of Seismology UIPE RAS, 123810, Bolshaya Gruzinskaya, 10, Moscow, Russia)

The essence of the new method lies in the zonation of the vast territories, including different tectonic units, according to the seismotectonic settings. Comparison of their spatial distribution and occurred earthquakes within their limits allows to determine the expected Mmax for most of them. Discovery of the similar seismotectonic settings within different tectonic units makes assessment of the prognostical Mmax to be possible. Thus, the seismological data from seismoactive region become applicable for areas to be poor provided with them. Obtained due this method results show that the seismic potential of tectonic active regions of South Europe is more high comparing to the observing seismicity. For instance our investigations suggest that predicted Mmax for the Alps is 7.3. Zones of predicted Mmax more than 6 are widely distributed there also. Since time the method is being elaborated the first result confirming its validity are obtained: the expected Mmax for number Earthquakes of last years in FSU were determined.

A NEW PREDICTIVE RELATIONS FOR EARTHQUAKE GROUND MOTIONS IN EXTENSIONAL TECTONIC REGIMES

P Spudich, JB Fletcher, M Hellweg, J Boatwright, WB Joyner, TC Hanks, DM Boore, A McGarr, LM Baker, and AG Lindh (all at: USGS MS977, Menlo Park, CA 94025 USA)

We present a new predictive relation for horizontal peak ground acceleration and 5%-damped pseudo-velocity response spectrum derived from earthquake ground motions from magnitude 5.0-7.0 events in extensional tectonic regimes including Italy, Greece, The Netherlands, and Israel. Extensional regimes are characterized by both normal faulting and strike-slip faulting events, both of which we used. Recording sites were classified 'rock' or 'soil,' following the classification scheme of Joyner and Boore (1981). As our distance metric we used the shortest distance from the receiver to the surface projection of the boundary of the fault rupture area. Our extensional regime data set does not span a magnitude range that is wide enough to determine the coefficients of magnitude dependent terms accurately. Consequently, we adopted the magnitude dependence determined from a larger data set by Boore et al. (1993, 1994) and used our extensional regime data set to constrain the distance and site dependent terms. Our new relation does not depend on earthquake mechanism. However, there is some evidence that normal faulting earthquakes may have motions slightly lower than strike-slip events.

HIGH-RESOLUTION COASTAL STUDIES OF RECENT EARTHQUAKES IN CENTRAL GREECE

I.S. Stewart and A.B. Cundy (Brunel University, Isleworth TW7 5DU, UK)
A. Dawson, S. Kortekaas and S. Dawson (Coventry University, Coventry CV1 5FB, UK)
H. Maroukian, K. Gaki-Papanastassiou, and K. Pavlopoulos (National University of Athens, 15784 Athens, Greece)
D. Papanastassiou (National Observatory of Athens, 11810 Athens, Greece)
I. Croudace (Southampton Oceanography Centre, Southampton SO14 3ZH, UK)

Regionally extensive palaeoseismic subsidence events are being increasingly recognised from detailed studies of Holocene coastal sequences along plate-boundary seaboards. Few studies, however, have attempted to characterise the coastal 'signature' of subsidence during earthquakes in the Mediterranean region. Although subject to moderate-magnitude earthquakes, low-lying coasts in the hangingwalls of normal faults in central Greece nevertheless witness metre-scale coseismic subsidence and tsunami-related marine incursion, both readily apparent in the Aegean region's microtidal littoral setting. Here, we present the preliminary results of high-resolution sedimentological and microfossil analyses, together with geochemical (^{210}Pb, ^{137}Cs) dating, of sediments in the immediate hangingwall of faults reactivated during the 1894 Gulf of Atalanti and 1981 Gulf of Corinth earthquakes. In particular, we examine the extent to which well documented coseismic subsidence events can be identified in the modern (10^1-10^2 yr) sediment record, and assess the wider utility of multi-proxy palaeoenvironmental approach in establishing long-term (Holocene) seismic chronologies within the Mediterranean domain.

SEISMIC CHARACTERIZATION OF THE SHALLOWER FORMATIONS USING MICROTREMOR MEASUREMENTS - THE LOWER TAGUS VALLEY REGION

P. Teves-Costa, I. Martins and C. Marreiros (Centro de Geofísica da Universidade de Lisboa, Rua da Escola Politécnica 58, 1250 Lisboa, Portugal)
L. Senos, D. Ramalhete and J. Costa-Nunes (Instituto de Meteorologia, Rua C do Aeroporto, 1700 Lisboa, Portugal)

The measurement of microtremors have been currently used in order to characterize the seismic behaviour of the shallower layers, according to the Nakamura (1989) methodology. This technique has the advantage to be very simple and it is specially useful in areas of low to moderate seismicity. The Lower Tagus Valley Fault has been responsible by several historical earthquakes, which caused great damage in the town of Lisbon (1344 and 1531) and, during this century, the 23.04.1909 earthquake (M_L = 6.0) was felt in almost all the country and produced the destruction of the entire village of Benavente. Nowadays, several small to medium villages exist in this valley, presenting a great concentration of population and, consequently, the seismic risk of this region has increased. This valley is composed mainly by alluvium deposits, reaching a depth of 60 meters. These low-impedance layers may have an important role, increasing the amplitude of the ground shaking for certain frequencies, during an earthquake. Microtremor measurements were performed in more than 300 sites, according to a grid of about 2 to 4 km wide in an area of about 1 728 km^2. The obtained results were correlated with the surface geology and also with the distribution of the intensities during the 1909 earthquake.

FUZZINESS IN DEFINITION OF SEISMIC INTENSITY AND POSSIBLE APPLICATION IN SEISMIC DESIGN

Ass. Prof. L. S. Timiovska, IZIIS, Skopje, Macedonia

ABSTRACT
The intensity degrees represent variables that cannot be clearly defined and can hardly be correlated with the exact values of maximum acceleration. In this domain, the FST approach seems to be quite adequate. This is due to the fact that this method is the most appropriate for operation with subjective assessments and provides output models that can easily be incorporated in the successive steps of the analysis. The seismic intensity to be defined as a global classification per degrees is fuzziness. As such, it should be considered as an fuzzy subgroup of the intensity set group. Presented in this paper are methods of a single degree and double degree multifactorial evaluations for seismic intensity. These methods enable scientific and concrete expression in a mathematical form. Namely, using of the level of fitting into the obtained phases of the intensity vector, could be found suitable parameters to incorporate in seismic design codex.

NH4 Hydrology of extremes and numerical weather predictions

Convener: Moore, R.J.
Co-Conveners: Llasat, M.C.; Siccardi, F.

ON THE COMBINED USE OF A MESOSCALE/CLOUD MODEL AND SATELLITE (METEOSAT AND SSM/I) OBSERVATIONS FOR STUDYING THE 1992 GENOA FLOOD EVENT

C. Accadia (Dip. Fisica, Universita "La Sapienza", Roma, Italy)
S. Dietrich (Fondazione per la Meteorologia Applicata, Firenze, Italy)
F.S. Marzano (Dip. Ingegneria Elettronica, Universita "La Sapienza", Roma, Italy)
A. Mugnai and G. Panegrossi (Istituto di Fisica dell'Atmosfera, CNR, Frascati, Italy)
J.P.V. Pojares Baptista (ESA-ESTEC, Noordwijk, The Netherlands)
L. Roberti (Dip. Ingegneria Elettronica, Politecnico di Torino, Torino, Italy)
E.A. Smith (Dept. of Meteorology, Florida State University, Tallahassee, Florida, USA)
G.J. Tripoli (Dept. of Atmospheric and Oceanic Sciences, University of Wisconsin, Madison, Wisconsin, USA)

A numerical simulation of the September 27, 1992 Genoa flood event has been carried out using the three-dimensional, time-dependent cloud mesoscale model University of Wisconsin - Non-hydrostatic Modeling System. The detailed thermodynamical and microphysical outputs of the simulation have been also used as an input to a radiative transfer scheme, so as to compute the multispectral upwelling microwave brightness temperatures that would be measured by the space-borne four-frequency (19.35, 22.235, 37.0, and 85.5 GHz) Special Sensor Microwave Imager (SSM/I) radiometer. Actual SSM/I observations of the flood event have been analyzed by means of a physically-based precipitation retrieval algorithm making use of the cloud-radiation dataset for the simulated event. Results of the model simulation will be discussed and compared with satellite (Meteosat and SSM/I) observations and retrieval.

A WATER-BALANCE STORM MODEL FOR SHORT-TERM RAINFALL AND FLOOD FORECASTING AT THE CATCHMENT SCALE

V.A. Bell and R.J. Moore (Institute of Hydrology, Wallingford, OX10 8BB, UK)

A simple two-dimensional rainfall model, based on advection and conservation of mass in a vertical cloud column, is investigated for use in short-term rainfall and flood forecasting at the catchment scale. The model is capable of assimilating weather radar, satellite infra-red and surface weather observations, together with forecasts from a mesoscale numerical weather prediction model, to obtain frequently updated forecasts of rainfall fields. Such data assimilation helps compensate for the simplified model dynamics and taken together provides a practical real-time forecasting scheme for catchment-scale applications. Various ways are explored for using information from a numerical weather prediction model (16 km grid) within the higher resolution model (5km grid). Model variants considered range from simple persistence and advection methods to different forms of the dynamic rainfall model. The results obtained from two convective events over southern Britain show that (i) a simple advection-type forecast may be improved upon by using multiscan radar data in place of data from the lowest scan, and (ii) advected, steady state predictions from the dynamic model, using 'inferred' updraughts, provides the best performance overall. Updraught velocity is inferred at the forecast origin from the last two radar fields, using the mass-balance equation and associated data, and is held constant over the forecast period. This approach proves superior to the buoyancy parameterisation of updraught originally employed. Selected rainfall forecasts are used as input to a catchment flow forecasting model to assess their effect on flow forecast accuracy.

HYDRO-SEDIMENTOLOGICAL ANALYSIS OF THE '96 APUANIAN ALPS FLASH-FLOOD EVENT

F. Castelli (Istituto di Idraulica, Università degli Studi di Perugia, Italy)
I. Becchi, E. Caporali and B. Mazzanti (Dipartimento di Ingegneria Civile, Università degli Studi di Firenze, Italy)
L. Castellani (Università degli Studi di Firenze, Sede di Prato, Italy)

The precipitation occurred on June 19, 1996, over the mountain watersheds of the Apuanian Alps (Central Italy) produced disastrous flash-floods along several streams, together with diffused and disruptive slope instability phenomena (soil slips and debris flows). Pluviographic records of the event show the exceptional character of point rainfall. On the other side, particular ground evidences suggest that the short-scale spatial rainfall distribution, not fully resolved by the point measurements, should also have had an important role in producing such dramatic effects. These considerations, among others, prompt for a probabilistic/distributed approach to the analysis of the event's dynamics. A Monte-Carlo procedure is used to estimate the probability of flow rates and slope failures all over the area. The forcing noise is provided by the stochastic generation of rainfall maps constrained to point observations, while the non-linear filter is given by a distributed, physically based, hydro-geo-sedimentological model. Various ensembles of simulations are generated with different hypotheses on the correlation and intermittency structure of the rainfall field. The obtained results are then discussed and compared with the available measures of the ground effects (location and extent of soil slips and debris flows, stage records at a river section and at a reservoir).

REGIONAL HYDRODYNAMICAL vs. LOCAL THERMODYNAMICAL INFORMATION IN BASIN QPFs BY ANALOG SORTING TECHNIQUE

S. Guilbaud and Ch. Obled (Laboratoire LTHE, Grenoble, France)
M.C. Llasat and J. Gibergans (Universidad de Barcelona, Barcelona, Spain)

Daily rainfall forecasts is issued every morning by the Water Ressources Service of Electricité de France, in charge of the management of mountainous catchments in France. The method is based on an analog sorting technique: meteorological situations similar to the current one, in terms of the 700 and 1000 mb geopotential fields at 0 h, are extracted from an historical data file (1953-1993). Then, the precipitation forecat is calculated, for each catchment separately, by using the empirical distribution function derived from the analogues' precipitation observed.
Another paper presented in this meeting will show some improvements of this model when using the 700 and 1000 mb geopotential data only. Then, the introduction in the analogy criterion of thermodynamical local information, has been tested, thanks to a cooperation between the LTHE and the University of Barcelona. This local information is elaborated from the data of a radiosounding presumably representative of the region (e.g. Nimes for the Southeast). After the quality control of the data, the information is used for a second level of selection: after sorting out 50 analogues based on the 2 geopotential fields 700 and 1000 mb only, another selection is made using an euclidean distance including this more local information. Encouraging results have been found when using raw data especially for basins close to Nimes. And, the same is currently done with more elaborated indexes, hopefully more correlated with heavy rainfall.

DRAINAGE DESCRIPTION IN REAL TIME FLOOD FORECAST

C. Calore, P. La Barbera and G. Roth (Institute of Hydraulics, University of Genoa, Montallegro 1, 16145 Genoa, Italy)

In last years much attention has been devoted to the study of the interaction between climate and soil features in shaping the morphology of natural channel networks. The importance of the morphology in the analysis of the catchment hydrological response is supported by the development of both flood hydrograph and river network evolution models. Informational entropy concepts are useful to explain hydrological phenomena and to understand the response at the basin scale: the river network informational entropy can be associated to the hypothesis that water discharge is the main source of information used by the drainage system to adjust its configuration, i.e., the tendency of the basin to shape its form in order to spend the least amount of energy to produce and transfer runoff. This concept is applied to investigate the informational content associated to geomorphologic data through Geographic Information Systems and to find out an optimal scale criterion for both the drainage network representation and the modeling, through a distributed approach, of the catchment hydrological response. The results allow to balance the conflict between the increase in the amount of data and the necessity to reproduce the basin structure and response. This conflict is enhanced in real time forecast of extremes in small catchments, characterized by a short time interval between the prediction and the flood event. The properties of the proposed entropy measure are finally investigated with reference to two different approaches. The first is developed with reference to a single basin while the second presents a multi basin approach.

DAILY RAINFALL IDENTIFICATION BY USING AN ANALOGOUS METHOD OVER LOCAL THERMODYNAMIC DATA

José Gibergans Báguena, Maria-Carmen Llasat, Department of Astronomy and Meteorology, University of Barcelona, Spain
J.Y. Rodriguez, EDF-DTG, Toulouse, France*

The objective of this paper is to show the application of local thermodynamic variables obtained from radiosounding ascents, in the classification of daily rainfall. The radiosounding station selected for this study has been Nimes (France). These data have been provided by the LTHE from Grenoble, and are extended from 1953 until 1983, it is to say, 30 years with data at 00 UTC and 12 UTC. Daily rainfall for this period has been provided for the Water Resources Service of Eléctricité de France. Taking into account that some days are lost or some radiosounding data are wrong, before to begin the statistical and meteorological analysis, the serie has been submitted to a quality control. Once the bad data are changed, interpolated or eliminated, an analogous criterion has been applied to the next variables: a) precipitable water mass between surface and 850 hPa, 850hPa and 700 hPa, 700 hPa and 500 hPa and surface-500 hPa; b) Difference of the equivalent potential temperature between surface and 950 hPa, 950 hPa and 850 hPa, 850 hPa and 700 hPa, 700 hPa and 500 hPa; c) Level of isocero, Richardson number, shear, CAPE and maximum vertical wind velocity; d) Instability indexes: SI, LI, KI, TTI, TTHI, SWI, SHEAR. The results obtained have allowed to select the most representative thermodynamical variables witch gives a conditionnally probabilistic distribution for daily rainfall amount.

BASIN DAILY QUANTITATIVE PRECIPITATION FORECAST BY AN ANALOGUE TECHNIQUE

S. Guilbaud and Ch. Obled (Laboratoire LTHE - Grenoble , France)

This rainfall forecast method is based on an analog technique: situations, similar to the current one in terms of the 700 and 1000 mb geopotential fields at 00 h, are extracted from an historical data file (1953-1993). Then, the precipitation forecast is elaborated for each catchment by using the empirical distribution function derived from the analogues' precipitation observed on the catchment.
Input data have been provided as the 700 and 1000 mb geopotential at 37 stations over western Europe, or condensed into their 2x12 first Principal Components, or also interpolated into regular grids. These candidate predictors are considered at 0 and 24 h to explain the daily precipitation amoungs starting at 08 h. The similarity criterion was first an Euclidean distance involving all the variables. Then, an automatic screening and weighting of the variables entered in the criterion has been performed for each catchment and significants improvements have been found. But the Teweles-Wobus score, specially designed for fields in grid points, has also been used to sort out the analogues. After the optimization of the size of the grid and its position relative to the catchments, results a little better than with the previously optimized Euclidean distance, have been found.
This approach is used by the Water Ressources Service of Electricité de France for the management of french mountainous catchments: daily rainfall forecasts are issued every morning to set up alert. The tested improvements will be implemented soon, taking into account new algoritms and input data in gridded form.

ANALYSIS OF HEAVY RAINFALL IN THE FRENCH ALPS : MAPPING OF RAINFALL HAZARD

KIEFFER Anne, BOIS Philippe, L.T.H.E. (INPG, UJF, CNRS, UMR 5564) [B.P.53 Domaine Universitaire F-38041 GRENOBLE Cedex 9]

In the French Alps, 90 rain-gauges stations provide precipitation data over short time steps (1 to 24 hours) and 463 pluviometers provide daily precipitation data for 24 hours. Thanks to this dense network, accurate maps of heavy rainfall for 24 hours can be generated. It would be therefore interesting to deduce characteristics of short rainfall from the daily one's.
As a result it is shown that linear relationships exist between 24 hours characteristics and 12 hours and 6 hours respectively, but not for shorter time steps. It is thus difficult to estimate extreme event characteristics for shorter time step then 6 hours and we need their measurements. Therefore we want to find an other solution to obtain reliable maps for short time steps.
In order to improve mapping, we search relationships between heavy rainfall and variables describing topography, like elevation, exposure... We look for linear relationships between this variables.

Spatial Database to Assess Design Flow Rates in the Walloon Region (Belgium)

S. LAIME (Faculté Universitaire des Sciences Agronomiques de Gembloux, Unité d'Hydraulique Agricole, 2, Passage des Déportés, 5030 Gembloux, Belgique)
Prof. S. DAUTREBANDE and B. MOEREMANS (Faculté Universitaire des Sciences Agronomiques de Gembloux, Unité d'Hydraulique Agricole, 2, Passage des Déportés, 5030 Gembloux, Belgique)

Managing and planning waterways and catchments require the setting up of efficient hydrologic tools. To this end, the Unité d'Hydraulique Agricole of the Faculté Universitaire des Sciences Agronomiques de Gembloux has combined a Geographic Information System, covering the whole Walloon Region, with the hydrologic model SWRRB-WQ, adapted to the Belgian conditions.
Associating the model with the GIS provide us with geomorpho-hydrologic information, spatially distributed on the studied basins, as well as design flow rates and daily flow rates. Let us underline that soil moisture is one of the variables of the model SWRRB-WQ and that it has an influence on the runoff rate, through a digital parameter : CN (curve number). The latter comes from the method used by the American Soil Conservation Service (SCS). Using the geographic database together with the model allows us to carry out a regional analysis which is linked to the catchment planning.

SHALLOW LANDSLIDES TRIGGERED BY HEAVY RAINSTORMS: A DISTRIBUTED HYDROLOGIC APPROACH

M. C. Rulli, G. Menduni and R. Rosso (DIIAR, Politecnico di Milano, Piazza Leonardo da Vinci 32, I-20133 Milano, Italy, E-mail: cristina@idra1.iar.polimi.it)

Hydrology of shallow landslides is approached using a spatially distributed framework. The usual topographic representation by grid models is shown to provide unrealistic boundary conditions for soil and water mass movements along hillslopes. Therefore, a countour based representation of basin topography is introduced. The investigated area is subdivided into irregular finite elements bounded by adjacent contour lines and stream lines.The water and soil model includes the infinite slope stability equation, hortonian infiltration, weight of vegetation cover and root strength. Temporal and spatial scales are investigated using fine resolution terrain and storm data. Preliminary results yield the safety factor for each element for any time step. Model validation is performed on Vezza watershed. In this steep and forested basin of Tuscany, Italy, on June 19, 1996, heavy rainstorms triggered a number of rapid shallow landslides which caused heavy damages and several victims. The spatial distribution of estimated safety factor is able to reproduce that of mass movements for examinated storm field. A comparison between the estimated safety factors and the observed events shows a good agreement and seems to be quite encouraging for future developments.

STATISTICAL ANALYSIS OF HEAVY RAINFALL IN THE FRENCH ALPS : SEASON OF HIGHEST RAINFALL HAZARD

KIEFFER Anne, BOIS Philippe, L.T.H.E. (INPG, UJF, CNRS, UMR 5564) [B.P.53 Domaine Universitaire F-38041 GRENOBLE Cedex 9]

In the French Alps, monthly maxima are available at 90 rain gauges locations over short time steps (1 to 24 hours) and at 463 pluviometers locations (data for 24 hours). The record period ranges from 10 to 87 years. Using several possible fitting method, the dataset allow the calculation of rainfall for return period from 2 to 100 years.
The method used to evaluate heavy rainfall with this data will be described. We mark out seasons which exhibit the highest rainfall risk. These seasons depend not only on the time step, but as well the location of the rain gauge in the study area. The question is : shall we delineate seasons for each location, for groups of location or the whole domain ?
Once this season is defined, we evaluate values of heavy rainfall with the Gumbel's law. The sample considered is built with the monthly maxima of the season with the highest rainfall hazard.

METHODS FOR SNOWMELT FORECASTING IN UPLAND BRITAIN

R.J. Moore, V.A. Bell, R.M. Austin and R.J. Harding (Institute of Hydrology, Wallingford, OX10 8BB, UK)

Snow, whilst not a dominant feature of Britain's maritime climate, can exert a significant influence on major floods through its contribution as snowmelt. Flood warning systems which fail to take account of melting snow can prove highly misleading. Interim results of a study on methods for improved snowmelt forecasting using trial catchments in upland Britain are reviewed. The snowmelt module, called PACK, incorporates a range of melt formulations, a storage mechanism based on the critical liquid water concept, and a partial cover model for shallow packs. This is coupled to lumped or distributed catchment models. Digital terrain models are used to support model configuration including elevation zones, controlling melt through temperature lapse rates, and isochrones, controlling flow propogation through the catchment. Data assimilation in real-time is accomplished by a novel updating scheme involving operating a "point" PACK model at the snow measurement site in parallel to PACK models in the catchment model, with point model errors being transferred using a proportioning scheme to adjust the snowpack water contents of the catchment model. This proves of particular value when using hourly measurements from a snow pillow. Whilst an energy budget melt formulation proves best, given reliable weather sensor data, a simple temperature index melt equation proves nearly as good and probably preferable in practice. The main melt can occur in almost equal measure by sensible heat exchange and by latent heat of condensation, as warm air near saturation in cloud condenses on the snowpack, with net radiation making little contribution.

PREDICTION OF EXTREME EVENTS: CASE OF FLOODS AND DROUGHTS

Jose D. Salas and Bonifacio Fernandez.

Estimation of exceedance probabilities and risk of failure are important for many water resources projects. For simple extreme events calculation of such quantities are simpe and well known. However, for complex extreme events, such as for dependent floods and droughts, the estimation of such quantities may be combersome. In this paper, we present a general approach which can be applicable for a wide number of cases. The approach is based on a recursive technique for estimating event probabilities and a Markov assumption for the underlying hydrologic process. The technique is illustrated with some applications for floods and droughts.

DESIGN OF RADAR/RAINGAUGE NETWORKS FOR HYDROLOGICAL USE

S.J. Wood, D.A. Jones and R.J. Moore (Institute of Hydrology, Wallingford, OX10 8BB, UK)

The dense network of 49 raingauges over the 132 km^2 Brue catchment in Somerset is used to examine the accuracy of rainfall estimates obtained from raingauges, from weather radar and from a combination of the two. A super-dense network comprising eight gauges within a 2 km grid square is employed to obtain a "true value" of rainfall against which the 2 km radar grid and a single "typical gauge" estimate can be compared. Accuracy is assessed as a function of rainfall intensity, for different periods of time-integration (15 minutes, 1 hour and 1 day) and for two 8-gauge networks in areas of low and high relief. The catchment gauge network is used to provide the "true catchment rainfall" and, in a similar way, the accuracy of a radar estimate (a weighted average of radar pixel values) and a single "typical gauge" estimate of catchment rainfall evaluated as a function of rainfall intensity. For 4 mm of rain in 15 minutes the standard error of a single gauge varies from 35% for a 2 km square to 65% for a catchment estimate, noting that the area ratio involved is 1:33. Combination of a single gauge and a radar estimate is used to obtain recalibrated radar estimates, with the "calibration factor" varying dynamically from one time-frame to the next. Comparing this dynamic recalibration with a long-term climatological correction indicates the distance from a gauge over which the dynamic recalibration is useful. The results provide valuable guidance on the density of raingauge network to employ in combination with a weather radar for flood estimation and forecasting.

NH6/NP4.2 Coherent structure and natural hazards

Convener: Moiseev, S.S.
Co-Convener: Mendes-Victor, L.A.

TWO-PHASE MODELS OF GRAVITATIONAL AVALANCHE-TYPE FLOWS

A.N.Bojinski, A.N Nazarov
(Moscow State University, Geographical Faculty, 119899, Moscow, Russia)

The problem of construction of the mathematical models describing the motion of gravitational avalanche-type flows considered as two-phase continuum media is discussed. These flows are: snow avalanches (snow and air), debris flows (water and debris material), slushflows (snow and water). The equations of mass and impulse conservation for each phase and for the whole mixture are written. The phase transitions are excluded. A term due to phase interaction takes into account in dynamic equations. This term is assumed proportional to a difference of phase velocities for avalanches and debris flows. The one-dimensional hydraulic type model based on averaged all quantities over cross section of flow is presented for debris flows. The liquid phase is modeled with a viscous fluid and the phase of debris inclusions is considered like a dry continuum media. It is convenient to treat slushflows within frameworks of two-layered model, namely the upper layer presents the floating snow in water and the lower one is a pure water. The interaction between these layers and entrainment of new snow mass into flow are taken into account. Two-layered model of mixed-type snow avalanche allows to study an occurrence and evolution of a powder cloud due to mixing with air on the top of flowing snow. A friction and mass transfer between layers are taken into account. Two-phase models permit to estimate a diffusion of phases in flows and to explain a series of effects, in particularly, the retardation of debris phase and a run away water along deposition zone and so on. The results of numerical modelling are given.

ON THE HELICITY GENERATION IN SHEAR FLOWS IN THE EXTERNAL MAGNETIC FIELD

O. Chkhetiani and S.S. Moiseev (Space Research Institute, RAS, Profsoyuznaya st., 84/32, 117810 Moscow, Russia)
E. Golbraikh and A. Eidelman (Center for MHD Studies, Ben Gurion University, P.O.B.653, Beer-Sheva 84105, Israel)

We have studied helicity generation in magnetohydrodynamic (MHD) systems with a mean flow and external transverse homogeneous magnetic field (**B**||**z**). It is shown that the presence of transverse gradient of the mean flow velocity (v_0||x) along y- and z-axes is a sufficient condition of the appearance of non-zero helicity in such a system. We compare the obtained results with experimental data on MHD flows received under laboratory conditions and in the Earth's atmosphere.

LABORATORY SIMULATION OF HELICAL TURBULENCE AND POLLUTION TRANSFER IN THE ATMOSPHERE

A. Eidelman, H. Branover and E. Golbraikh (Center for MHD Studies, Ben Gurion University, P.O.B.653, Beer-Sheva 84105, Israel)
V. Ponomarev (Institute of Atmospheric Physics, RAS, Pyzhevsky per. 3, Moscow, 109117, Russia)

Experimental study of anisotropic turbulence generated under constraint in magnetohydrodynamic flow revealed a similarity in its energy spectra and wind spectra exponents. Theoretical investigations of helical turbulence have led to the interpretation of these results, particularly, -7/3 exponent, local disturbances, etc., in the framework of the helical model. Numerical simulation of atmospheric pollution transfer taking into account -7/3 velocity spectral scaling has revealed a respective change in passive scalar dispersion scaling. The computation of the pollution transfer parameters under such turbulence shows an essential difference from the case of -5/3 Kolmogorov's turbulence. The comparison with the available data of atmospheric observations shows their good agreement with modeling results.

SCALING PROPERTIES OF RADIOBRIGHTNESS TEMPERATURE FIELD OVER TROPICAL CYCLONES

N. Erokhin, M. Mityagina and S.Moiseev (Space Research Institute, Profsouznaya Str.84/32, 117810 Moscow, Russi a)
B. Petrenko (Institute of Radio Engineering and Electronics, Mohovaya 11, 103907 Moscow, Russia)

The data processing of radiobrightness temperature fields over tropical cyclones at the square of 400x400 pixels are performed. The studying of scaling properties o f RBT-fields representing the large-scale coherent structure and small scale chaot ic subsystem is given on the basis of space structural functions and generalized dimensions analysis at the space scale from 2.5 km to 750 km. The existence of inertial range with power law dependence is demonstrated and scaling exponents a re calculated. The comparison with background RBT-foeld (outside typhoon) is made. The data processing result is interpreted using the physical concept of natural haza rds diagnostics elaborated early in IKI RAS. Support of this work was provided by th e RF Ministry of Science and Technical Policy (grant Vortice-2).

GRAVITO-ELECTRODYNAMICS OF DUST IN AN ELECTRIC CUSP

Hiroshi Kikuchi (Nihon Universty, College of Science and Technology, 8, Kanda-Surugadai, 1-chome, Chiyoda-ku, Tokyo 101, Japan)

An electric cusp or electrically neutral point (line or sheet) is analogous to a magnetic cusp and has been introduced by the author with the concept of electric field line merging-reconnection for the last decade. It has been shown that any perturbation exerted on an electric cusp, typically the injection of dust into a cusp can lead to electric field line merging-reconnection. In other words, the source-origin of electric reconnection is an electric cusp that becomes a bifurcation point for the electric potential and at the same time a saddle point for the electric field, necessarily being capable also for a source-origin of chaos. In this paper, additional perturbation by an external gravitational field is considered, in particular focussing on how the behaviour of dust in an electric cusp will be modified by an external gravitational field, namely 'gravito-electrodynamics of dust for tenuous plasmas is discussed with its relevance to laboratory and cosmic dusty plasmas. The criterion of ordered and chaotic behaviours of dust grains in a periodically cusped structure is indicated. As a complementary study, electric potential and field profiles for the case when a spherical or cylindrical dust is placed in a point or line cusp are obtained in detail.

ALLOCATED IMPERFECTIONS OF DEVELOPED CONVECTIVE STRUCTURES

A.V.KIRICHOK, V.M.KUKLIN
Department of Physics and Technology,Kharkov University, 4 Svobody Square, 310077 Kharkov, Ukraine

It is well known, that in nonequilibrum convective mediums are formed periodic (in real mediums, such as atmosphere or mantle of the Earth, solar crown etc., quasiperiodic) structures. Their formation, as a rule, has a threshold character and is connected with exceeding of Rayleigh number Ra of some critical value Ra_1. The amplitude of an arising primary structure thus is proportional to $\epsilon_1 = (Ra - Ra_1)/Ra_1$. During growth of a primary structure there are appear the conditions for development of secondary instability (of modulation type), which leads to formation of large-scale regular imperfections, embedded in the primary structure. By analogy, it is possible to enter a control parameter of secondary instability R_2, to determine its critical value R_2 and level of its above-threshold. Obviously, R_2 is function of intensity of a primary structure. Easily to show, as in the appropriate time scales, ϵ_1 and ϵ_2 are the increments of the appropriate instabilities.

Analysis of behaviour of some nonlinear systems (in particular, con-vective unstable layer of a liquid with the rigid boundaries poorly conducting heat [1]) has shown, that a ratio of intensities of developed secondary and primary structures (the so-called imperfection level of a primary structure) appears about ϵ_2. The same order relation takes place between a characteristic scale of a primary periodic structure and characteristic size of a regular imperfection.

DUSTY PLASMA SOLITONS IN THE IONOSPHERE

A.N.Kotsarenko, S.V.Koshevaya
Instituto Nacional de Astrofisica , Optica y Electronica (INAOE) , P.O Box 51&216, Z. P. 72 000, Puebla, MEXICO ,
e-mail:svetlana@inaocp.mx
N.Ya.Kotsarenko
Instituto de Geofisica, UNAM, Coyocan 04510, Mexico D.F., MEXICO
e-mail:kotsaren@tonatiuh.geofcu.unam.mx

Last time different dusty plasma structures in the space plasma are investigated.Typical examples of such structures are the spokes of the rings of the giant planets (Saturn, Jupiter),the condensations in the plasma cometary tail.In this report electrostatic spatially limited dusty plasma soliton structures in the low altitude ionospheric plasma are investigated.Spatial form,longitudinal and transverse sizes,dependence of the velocity on the soliton's amplitude is founded.The obtained results are used for the explanation of the bubbles in the low altitude ionosphere .

NUMERICAL ANALYSIS OF LARGE-SCALE CONVECTIVE MOTIONS IN A THIN FLUID LAYER WITH THERMALLY INSULATED BOUNDARIES

G.V.Levina (Institute of Continuous Media Mechanics, Ural Branch RAS, Acad. Korolev St..1, Perm 614013, Russia)
L.V.Shestakova (Perm State University, Departement of Mathematics and Mechanics, Bukirev St..15, Perm 614005, Russia)

Results of numerical solution to the equations of a semiempirical model (it has been presented at XXI General Assembly of the European Geophysical Society) for turbulent convection by the finite difference method are presented. The mathematical model considered describes the generation of the large-scale vortices in a thin fluid layer. This process is caused by the action of anomalous heat transfer mechanism, which manifests itself under conditions of high intensity of small-scale turbulent convection and low level of heat loss through boundaries. The influence of various physical factors (the small-scale turbulent convection intensity, the degree of boundaries heat insulation, the rotation, the intensity and form of initial heat perturbation, and etc.) on large-scale instability evolution has been investigated. The obtained results have been compared with our earlier theoretical predictions and with our experimental data on laboratory modeling of tropical cyclones, and have verified them. This work is supported by RFFI under Grant N 95-01-01094a.

INTERACTION OF COHERENT WAVE WITH HELICAL TURBULENCE IN STRATIFIED SHEAR FLOW

S. S. Moiseev and **V.G. Pungin** (Space Research Institute, Profsoyuznaya 84/32, 117810 Moscow, Russia)

Interaction between large-scale internal wave and small-scale helical turbulence in plane Couette flow of fluid with statically stable uniform density gradient in gravitational field is studied basing on a set of equations for scalar and quasi-scalar wave fields and for helicity of turbulence. It is shown that helical turbulence provides coupling of scalar and quasi-scalar wave fields leading to exponential growth of wave amplitude, A, goverened by equation of the type $\dot{A} \sim S\alpha A$, where $\dot{A}$ denotes time derivative, S is shear of mean flow velocity, α is a parameter, proportional to helicity of small-scale turbulence. For this parameter algebraic equation $\alpha = \alpha_0 \left(1 + (A/A_0)^2\right)$ is derived in the case when small-scale turbulence is excited by external random helical force and linear stability parameter of mean flow is close to its critical value, dividing regimes with and without inviscid dissipation of linear disturbances in critical layer. This system of equation describes acceleration of wave growth due to its backward action on turbulence, i.e. wave-turbulent instability. This work was supported by RFBR under Grant 96-02-19506.

AMPLIFICATION OF FLUCTUATIONS AND CURRENT DYNAMO DUE TO HELICAL AND CHIRAL EFFECTS IN GEOPHYSICAL AND PLASMA-LIKE MEDIA

S. S. Moiseev, A.V. Belyan, V.G. Pungin and O.G. Chkhetiani (Space Research Institute, Profsoyuznaya 84/32, 117810 Moscow, Russia)

It is well known that in conducting medium with small-scale helical turbulence generation of large-scale magnetic field is possible. But it has not been so far taken in account that correlation function of microcurrents must also have helical part. The present work consider more general case, when not only mean motion but also conducting components possess nonzero mean helicity. Dispersion equation for helical motions is studied, including inhomogeneous case. Criteria for development of instability are found.
Further in the work chiral media are considered and effects topologically close to helical ones are analyzed. It is shown that in such media ranges of waves exist, in which fluctuations can be anomalously amplified.
Behaviour of conductivity in fluctuating media with helical and chiral effects as well as influence of ponderomotor forces on mean motion in such cases are analyzed. This work was supported by RFBR under Grant 96-02-19506.

LABORATORY MODELING STABILITY OF THE LARGE-SCALE INTENSE BAROTROPIC ATMOSPHERIC POLAR ROSSBY VORTICES

M.V.Nezlin, A.Yu.Rylov, K.B.Titishov, and G.P.Chernikov (RRC "Kurchatov Institute", Russia, 123182 Moscow, Kurchatov Square, 1)

Laboratory modeling stability of the large-scale intense barotropic atmospheric polar Rossby vortices has been carried out. Vortices were created by the method of sources of mass (for anticyclones) and sinks of mass (for cyclones). The vortex sizes were greater or approximately equal to the Obukhov-Rossby radius. Water having a free surface was used as a working liquid. The experiments have shown that the vortices did not move from the paraboloid pole (where they were created). Dependence of the e-folding time (T) for the maximal linear rotation velocity of a vortex on the thickness (Ho) of the water layer has had the following peculiarities: (1) when Ho decreases from 7.5 cm to zero, the value of T decreases smoothly from 45 sec to To = 18 sec (for anticyclones) and from 38 sec to To = 12 sec for cyclones; (2) when Ho approaches zero, the value of T does not approach zero (as it takes place in the absence of the liquid free surface), but remains a rather large. These regularities are well explained by the theory of viscous Rossby vortex damping, with due account for the free surface.

ATMOSPHERIC AND LITOSPERIC RESPONSES ON LAUNCHES OF HEAVY SPACE VEHICLES, CONNECTED WITH CATASTROPHIC HAZARDS

Sergey I. Rybnicov
Moscow State Aviation Institute (Technical University)

A heavy space vehicle launch is accompanied by formation of aerosol with participation of fuel combustion products. The aerosol is carried by wind on a large zone, descends, its particles influences on a troposphere lot as nuclei of condensation and crystallization of moisture. This causes an increase of cyclonical activity in the influence zone, in particular appearance frequency increase of strong and catastrophical precipitation and wind, turning of wind.
Coherent oscillations of atmospheric pressure over tectonic plates provokes seismic reactions in their borders, at that number affects on formation of strong earthquakes there. At the second half-wave of the oscillations grows seismisity in compressed borders (the main influence), at the first and party at the third half-wave it grows in strained them. Coherent oscillations in the environment provokes an infrastructure catastrophe frequency increase.
The heavy rockets launches further to switching on coherent trigger phenomena of realization of natural environment instability. The report will contain experimental, statistical characteristics of catastrophe-formative meteorological and seismic responses on launches of the heaviest rockets in Florida, meteorological and microseismical responses on launches of Russian rockets which belong to a middle their class, as well as some methods to decrease the negative consequences of space activity.

NH7 Natural hazards in active volcanic regions

Convener: Macedonio, G.

MUDFLOW PHENOMENA IN VOLCANIC ACTIVITY REGIONS.

Budarina O. Moscow State University.

Within the framework of the research on the project "The Geography of the World Mudflow Phenomena" the data on mudflow phenomena in the areas of strong volcanic activity has been collected and analized at the Geography Faculty of Moscow State University. Volcanogenic mudflow (lahars) are widely spread all over the world, and they belong to extremely dangerous nature phenomena. The moving mudflow masses are by hundreds of times than the size of ordinary mudflows. In some cases the mudflow transit and accumulation zones can occupy hundreds of kilometres. They lead not only to distruction but to numerous losses of human lives (the eruption of vlk. Ruis in 1985, the eruption of vlk. Pinatubo in 1991 and 1994). In this paper the spreading of volcanic mudflows on the Earth and the characteristics of the volcanogenic mudflow genesis have been analized. Various mechanizms of mudflow formation caused by volcanic activity both in the state of eruption and calmness have been investigated.

THE SEISMIC CRISES AT MT.VESUVIUS DURING 1995 AND 1996

Castellano M., Bianco F. and Vilardo G. (Osservatorio Vesuviano - Via Manzoni 249, Napoli - Italy)
Ferrucci F. (University of Calabria, Cosenza - Italy)
Gresta S. (University of Catania - Italy)

An increased seismic activity at Mt.Vesuvius was recorded during two recent periods: August-September 1995 and March-April 1996. The Permanent Seismic Network, composed by 10 analog stations, was supported by up to 7 three-component temporary digital stations. An increase both in event's number and energy was observed. Four events with M≥3.0 were recorded; the earthquake with the maximum magnitude (M=3.4; the stronger event in the last two decade) occurred on 25 April 1996. The use of three-component seismometers allows to obtain very reliable hypocentral locations. The focal volume of the two seismic crisis not exceeds 5-6 km of depth below the crater area. Space-time distribution of earthquakes was performed to evaluate some temporal variation of energy release. No clear decreasing of S-P time at OVO station as indicator of migration of hypocenters was observed during the two crisis. Site response for some events was also calculated.

FORECASTING VOLCANIC HAZARDS USING PROBABILISTIC MODELS

Olivier Jaquet, Colenco Power Engineering Ltd
Simon Löw, ETH Zurich
Bruno Martinelli, ETH Zurich
David Gilby, Colenco Power Engineering Ltd

Assessments of the probability and the consequences of future volcanic activity are critical aspects when evaluating the safety of potential or existing nuclear power plant sites. Based on regional volcanic data, a new methodology was developed for the forecasting of volcanic hazards that allows the production of hazard maps at a given site. The approach comprises a) performing the estimation of the future mean frequency of eruptions for a given time scale; and b) producing maps of the probability of future volcanic events considering different scenarios (lava flows, lahars, ashes,...). The temporal and spatial variabilities of the volcanic events were characterised using geostatistical models. These models allow account to be taken of the observed spatial and temporal correlations of volcanic eruptions. The estimation of the mean frequency of eruptions and the probabilities related to the different scenarios were obtained using a Monte Carlo approach. Furthermore, topographic or meteorological effects that control some types of volcanic scenarios can be included. Finally, the obtained probability maps of future events serve as a backbone for the risk analysis that will determine the consequences of predicted volcanic activity at the site.

VALIDATION OF THE VOLCANIC GAS FLUX

François LE GUERN CFR. CNRS-CEA Avenue de la Terrasse 91190 Gif-su-Yvette France e-mail Francois.Le-Guern@cfr.cnrs-gif.fr
R. X. Faivre-Pierret, I.P.S.N.- CEA .Grenoble France

The fluxes of volcanic gas and aerosols are worldwide estimates in using a remote measurement of SO_2 . The accuracy of such a method is dependend on the invariability of the SO2 . Source measurements and modeling of the magmatic gases has pointed out the complex chemistry occuring during the gas to particle conversion occuring during the cooling of magmatic gases in the atmosphere. In order to validate these evaluations we used at the same time a tracer gas method, (SF_6) injected in the source. Applied on Mt Erebus (Antarctica) , Mt Etna (Italy) and Mt Satsuma Iwojima (Japan) This method gave different flux evaluation that can be explained by a different behaviour of the magmatic gas phase.
This method has been also used to simulate the emergency occuring in case of volcanic crisis as on the Volcano "La Soufriere" (French West Indies):where we were able to trace the diffusion of toxic gases along two preferencial channels.

CELLULAR AUTOMATA MODEL FOR LAVA FLOW SIMULATION

G.M. Crisci°, S. Di Gregorio^, A. Di Francia^, F. Nicoletta*, R. Rongo^
°Dip. di Scienze della Terra ^Dip. di Matematica *Dip. di Chimica
Università della Calabria, I 87036 Arcavacata, Italy

Cellular Automata (CA), a paradigm of parallel computing, represent an alternative to differential equations and are used for modelling and simulating very complex phenomena; CA models have been developed by our research group for the simulation of lava flows. We present SCIARA-2, our most efficient model, a two-dimensional CA model together with the simulation results of Mount ETNA eruption of 1991/2. Lava flows are viewed as a dynamic system based exclusively on local interactions with discrete time and space, where space is represented by square cells, whose specifications (states) describe physical and chemical characteristics (temperature, altitude, lava thickness, etc.) of the corresponding portion of space. At the time t=0, cells are in states which describe initial conditions; the CA then evolves changing the state of all cells simultaneously at discrete times. Input for each cell is given by the states in the adjacent cells; the outflow computation from the cells gives the evolution of the phenomenon. The comparison between the real and simulated events is satisfying within limits to forecast the surface covered by the lava

FORECASTS OF VOLCANIC ERUPTIONS FROM SUBCRITICAL ROCK FRACTURE

Christopher Kilburn, Dept of Geological Sciences, University College London, Gower Street, London WC1E 6BT, G.B.

Rock failure is fundamental to forecasting volcanic eruptions. Volcanoes are fractured, brittle structures in which fractures occur at all scales, from intragranular cracks to major faults. These fractures are preferred sites for deformation when rocks are strained by new magma arriving close to the surface.

An empirical formula, the Voight-Fukozono (VF) relation for material failure, has been proposed for describing measured pre-eruptive deformation rates. It is shown that the VF relation is a natural consequence of subcritical crack growth, here related to static rock fatigue under magmatic pressure. With this interpretation, pre-eruptive deformation is initially dominated by the appearance of new cracks but, as the strain rate accelerates, deformation is limited by the rate of crack extension. Eventually, the cracks coalesce to open a major dyke which then feeds an eruption.

Subcritical rock failure provides a plausible physical basis for using the VF relation to forecast volcanic eruptions. Over longer time periods, repeated edifice fatigue may also determine eruption frequencies at volcanoes, such as Etna, that are persistently charged with high-level magma.

LAVA FLOW DIVERSION USING EXPLOSIVES

François LE GUERN CFR. CNRS-CEA Avenue de la Terrasse 91190 Gif-su-Yvette France e-mail Francois.Le-Guern@cfr.cnrs-gif.fr
Lenhardt ABERSTEN C.A.E.M. Via Poma 2120129 Milano Italy

Complete success in arresting a lava front : has been achieved : in 1983 and in1992 on Mt Etna. Both diversions were obtained using explosives: 390kg in boreholes removed 200m3 of rock on 14 May 1983; more than 6.000 kg placed on the surface of the soil removed 50 m3 of rock on 26 May 1992. In 1983, we prevented the deterioration or uncontrolled detonation of the explosives, using a water cooling jacket or airguns. Since 1983, we have developed a more efficient method: the gravity charging.
By drilling, the explosive charges are placed as close as necessary from the active lava at any depth, confined in rows of holes that can easily produce big blocks of refractory lava , while, on the contrary, surface charges pulverise the rock without reaching the flowing lava.
Modern boring techniques make it possible to both drill and install the tubes. Boreholes with a diameter of 180mm make it possible to load 40kg of explosives per meter at any depth.
Boring equipmentt and compressors can be transported by air the heaviest equipment not exceeding 6,000kg.

LAVA FLOW IN A TUBE WITH A BIFURCATION

G. Macedonio and A. Longo (CNR-CS Geologia Strutturale e Dinamica dell'Appennino, Pisa, Italy I-56126)

During the 1991-1993 eruption of Mt. Etna, the lava flow posed under risk a town (Zafferana Etnea) lying along the natural lava flow path. To mitigate this risk, the Italian Civil Protection created an artificial bifurcation on the natural tube to divert the lava in an artificial channel. In this work, a Finite Element model was developed to investigate the dynamics of the lava flow at the bifurcation, for different geometries of the artificial and natural tubes. The model is based on the solution of the Navier-Stokes equations for an incompressible fluid with Newtonian rheology. Several simulations were performed to investigate the relationship between the effectiveness of the divertion and the geometry of the artificial channel. The model is able to estimate the mass flow rates of the magma through the two branches of the bifurcation as a function of the widths and slopes of the artificial and the natural channels. Preliminary results show that the effectiveness of the divertion is quite independent of the angle between the two branches of the bifurcation.

ON THE MECHANISM OF UNREST EPISODES AT CAMPI FLEGREI (ITALY) CALDERA: THE JOINT ROLE OF MAGMA CHAMBER AND SHALLOW AQUIFERS.

G. Mastrolorenzo, C. Troise, F. Pingue, S. Rossano and G. De Natale (Osservatorio Vesuviano,via A. Manzoni,249, 80123 Napoli, Italy)
F. Gaeta, F. Peluso, D. Castagnolo, D.G. Mita (MARS CENTER, Naples Italy)

A model is presented to explain the mechanism of unrest phenomena at Campi Flegr ei (Italy). The model consists of two effects: the first one is related to the elas tic response of the shallow crust to increasing pressure within a shallow magma chamber; the sec ond involves the thermofluid-dynamics of shallow aquifers in response to increasing pressure and/or temperature at depth. Fluid circulation in the geothermal system is inter preted by a monodimensional model simulating the thermodynamics of shallow aquifers. The thermofluid-dynamical model is based on parameters for the Campi Flegrei rocks w hich have been previously determined by laboratory experiments. The most important effects on the genesis of unrest episodes, as due to fluid ci rculation, are linked to the flow variation induced by stress and temperature changes produ ced by overpressure and/or increased heat flow in the magma chamber. The joint effect of the magma chamber and of shallow fluids allows to build a se mi- quantitative model for the interpretation of observed ground deformation and sei smicity, and of their time evolution. In particular, the time durations of the two phases of increasing and decreasing ground elevation can be easily explained in terms of the evolutio n of geothermal flow. It is further evidenced the needing for a better understanding of the effects of large stress increases on the modification of thermofluid-dynamic parameters of Campi Flegrei rocks

INTERPRETATIVE MODELS FOR GRAVITY VARIATIONS IN VOLCANIC AREAS

M. Mazzanti and M. Bonafede (Dipartimento di Fisica - Settore di Geofisica, Universita' di Bologna, Viale Berti Pichat 8, 40127 Bologna, Italy)

In the last years (1970-72 and 1982-84) two episodes took place at Campi Flegrei (C.F.), both characterized by significant ground uplift and gravity variations. Employing an elastic model with a spherical source of ground deformation applied to a stratified half-space, the contributions to gravity variations produced by the displacements of the surface, the subsurface layers and the deformation source were computed. These contributions and the measured (at C.F.) gravity residuals were compared, to draw inferences on the physical processes responsible for the deformation at C.F. Results show that neither an inflation of the source at constant mass nor at constant density can remove the discrepancy between the computed and measured gravity values. Employing a poro-elastic model in which the geothermal system is assumed to be responsible of the observed anomalies, computed residuals become compatible with measured values, due to the input of new fluid mass. The comparison between two stratified models reveals that gravity anomalies are not significantly sensitive to the detailed knowledge of the density stratification.

PHREATIC EXPLOSION HAZARD ASSESSMENT BY NUMERICAL SIMULATION

A. Neri (CNR-CS Geologia Strutturale e Dinamica dell'Appennino, Gruppo Nazionale per la Vulcanologia, via S.Maria 53, I-56126 Italy)
G. Macedonio (CNR-CS Geologia Strutturale e Dinamica dell'Appennino, via S.Maria 53, I-56126 Italy)

Phreatic explosions represent common and dangerous phenomena occurring in active volcanic and geothermal regions. In spite of this, the understanding of their dynamics and emplacement mechanism of their products is still scarcely tested and quantified. In the present work we try to simulate the dynamics of a phreatic explosion by using a transient, two-dimensional, multiphase flow model. Simulations describe the effects of an explosion of a mixture of superheated water vapor and ground fragmented particles into the atmosphere. The governing transport equations of mass, momentum, and energy are solved by a finite difference multifield scheme for both solids and gas phases. Several simulations have been performed assuming different initial conditions and system parameters. In particular, the effects of the explosion magnitude and energy, as well as the influence of system geometry, have been quantified. The model allows to analyze the timewise and spatial distribution of the ground-hugging particle flows generated by the explosion and to estimate their potential hazards in terms of dynamic pressure, particle concentration, and temperature. Further interesting information are related to the strongly transient dynamics of the explosion and its craterization effects suggesting new insights and interpretations of field evidence.

Recent Volcanic Eruptions Recorded on Seismograms Operated at Active Volcanoes in Hokkaido, Northern Japan

Yuichi Nishimura, Hitoshi Mori and Hiromu Okada (Usu Volcano Observatory, Hokkaido University, Sohbetsu 59, Hokkaido, Japan)

Hokkaido is an island located at the junction of Tohoku and Kurile island arc. Five volcanoes in the island recorded 18 eruptions with VEI=3 or more during this 350 years. At the present, five volcanoes are under continuous observation by Usu Volcano Observatory (UVO) using a telemetry system. These five volcanoes experienced eruption episodes under UVO's 20 years history; Komagatake (1996), Usu (1977-1982), Tarumai (1978-1981), Tokachi (1988-1989) and Me-Akan (1988, 1996). Since we have succeeded to install or upgrade the observation systems of each volcanoes fortunately before the most eruptions, we could evaluate some eruption parameters based on instrumental data. Volcanic tremors directly associated with continuous eruptions were observed at Usu (1977-1978), Tokachi (1988-1989), Komagatake (1996) and Me-Akan (1996) volcanoes. Amplitude variations of these eruption tremors were useful to evaluate the duration times of each eruption and rise and fall of their eruption powers. Explosion earthquakes and corresponding air waves were recorded at the 1988-1989 Tokachi eruptions. Comparison of origin times of these arrivals leaded to a conclusion that the air waves have always been generated about 1.0 sec after the occurrence of the explosion earthquakes.

Behavior of Historic Tsunamis of Volcanic Origin as Revealed by Onshore Tsunami Deposits

Yuichi Nishimura (Usu Volcano Observatory, Hokkaido University, Sohbetsu 59, Hokkaido, Japan), Naomichi Miyaji (Hokkaido National Agricultural Experiment Station) and Masaaki Suzuki (Dohto University, Junior College)

Volcanogenic tsunamis are rarely observed but known to be violent and destructive. According to the old documents, two historic tsunamis caused by volcanic eruptions attacked Hokkaido, northern Japan. They are the 1640 Komagatake event which killed more than 700 people, and the 1741 Oshima-Ohshima event which killed 1467 people. To obtain more information of these old tsunamis, we investigated onshore tsunami deposits associated with these events. Tsunami deposit is composed by beach sand carried up and deposited inland by a tsunami. Since spatial distribution and lithofacies of the sand layer would change distinctively with the distance from the sea, it is possible to identify tsunami deposit by sedimentary structure and granulometric characteristics. We traced the 1640 and 1741 tsunami deposits at outcrops, or by making pits or trenches, and estimated tsunami heights where no old documents are available. The followings are common properties to the tsunami deposits on dunes we studied. Generally, thickness and mean grain size of the sand layer decreases with distance from the sea. The layer is especially thick between two dunes. Accumulated sand contains original surface materials which eroded and carried by the tsunami.

NUMERICAL SIMULATION OF MAGMA ASCENT ALONG VOLCANIC CONDUITS

P. Papale (CSGSDA, via S. Maria 53, I-56126 Pisa)

The process of magma ascent along volcanic conduits during explosive eruptions is numerically simulated by solving the transport equations in the one-dimensional, steady, and isothermal assumptions. The physical model considers the non-equilibrium multiphase flow of a mixture of liquid magma, crystals and/or lithic fragments, and exsolving gas. The liquid magma is treated as a mixture of 10 major oxides plus dissolved water and carbon dioxide, and the gas phase as a mixture of water and carbon dioxide. The model is characterized by a strong coupling between fluid dynamic and constitutive equations, whereby the magma properties like viscosity, density, and gas solubility are calculated on the basis of the chemical composition of the liquid magma and its crystal content, and are allowed to vary along the conduit. The model predictions obtained by considering many different eruptive conditions reveal complex and sometimes non-intuitive relations between the selected initial conditions and the predicted flow parameter distributions. The composition of the liquid magma, the amount and composition of volatiles, and the crystal content, are found to be of major importance in determining the dynamics of magma ascent during explosive eruptions. The magma ascent model can be used to forecast the volcanic hazard at a given volcano. This is done through the definition of the conduit exit flow parameters which constitute the input to the models of magma dispersion in the atmosphere and formation and propagation of pyroclastic flows.

THE ROLE OF WATER AND MAGMA COMPOSITION ON THE EXPLOSIVE ERUPTION DYNAMICS

P. Papale and A. Neri (CSGSDA, via S. Maria 53, I-56126 Pisa - Italy)

The dynamics of explosive volcanic eruptions have been studied by simulating the ascent of magma along the volcanic conduit and the pyroclasts dispersion in the atmosphere. The conduit ascent model accounts for the steady, non-equilibrium and multiphase flow of liquid magma, crystals, and exsolving gas (water). The magma properties are calculated as a function of the composition in terms of ten major oxides plus dissolved water and the crystal content, and are allowed to vary along the conduit. Vent conditions obtained by such modeling constitute the input for the pyroclasts dispersion modeling. Column and pyroclastic flow dynamics are simulated by a two-dimensional, transient, two-phase model which accounts for the mixing of particles and hot water vapor leaving the vent. Several simulations have been performed by varying the initial conditions in terms of magma composition and water content. The results show an important role of both these parameters in determining the dynamics of the eruptions, and allow the interpretation of some common features of many volcanic deposits like the increase of the mean and maximum grainsize or the change from plinian to pyroclastic flow phases when the composition of the erupted magma is shifted toward less chemically evolved terms. The coupling between the conduit ascent and pyroclasts dispersion models allows the forecasting of the volcanic hazard at a given volcanic area, provided that the appropriate initial and boundary conditions can be evaluated.

THE DEVELOPMENT OF COMPOUND LAVA FIELDS AT MOUNT ETNA

M. **Polacci** (Dip.to Scienze della Terra, via S. Maria 53, I-56126 Pisa - Italy)
P. Papale (CSGSDA, via S. Maria 53, I-56126 Pisa - Italy)

The formation of compound lava fields is a common feature of basaltic volcanic areas such as Mount Etna and Hawaii. It is generally promoted by a break-in-slope which results into a decrease of the mean flow velocity and the rapid adjustment to new rheological conditions. In fact, on a steep slope the flow is generally focused into long-lived lava tubes or channels. On the contrary, in correspondence of a flat ground the propagation of a lava field is guaranteed by the continuos opening of new ephemeral vents, and by the overlapping of lava lobes or tongues the lenght of which is order of 10^{-1}-10^{2} m. At Mount Etna these flow units show a complex internal structure characterized by a succession of lava layers separated by gas-rich layers which occur in correspondence of vesicle alignments. Such internal structure enhances the thermal efficiency of lava flows from ephemeral vents, insulating the active moving core and preserving high lava temperatures. The evolution of a lava field may be thus envisaged as a spatial and temporal emplacement of a sequence of lava tubes. An example of this situation may be found in both the 1983 and 1991-93 Etnean eruptions, where the propagation of long-lived compound lava fields through a great number of small subarterial flow units gave origin to a source of natural hazards for some of the communities living on the flanks of the volcano. The detailed study of the structure of the described lava flows helps understand their emplacement dynamics and evaluate the associated volcanic hazard.

COMPUTER SIMULATIONS OF VOLCANIC GRAVITY-DRIVEN PYROCLASTIC CURRENTS ON SOMMA-VESUVIUS VOLCANO: DATA BASE OF ERUPTIVE SCENARIOS AND INVERSE ANALYSIS OF PAST ERUPTIONS.

Rossano, S., Mastrolorenzo, G., and De Natale, G. (Osservatorio Vesuviano, Via Manzoni 249, 80123 Napoli Italy)

We describe a numerical simulation of different types gravity driven pyroclastic currents on Somma-Vesuvius consisting of two integrated parts: forward and inverse approaches. The forward approach consists of the numerical generation of radial, one-dimensional flow lines from the vent, over a digitized topographic model of the Somma-Vesuvius area. The numerical flows are generated sampling a multi-dimensional matrix of dynamic and rheological parameters based on data from real eruptions. Analysis of the simulated flow patterns suggests that the pyroclastic flows, lahars and rockslide avalanches are compatible with a relatively dense Newtonian and Bingham flow models. The acceptable parameter values are confined within a relatively small range (moderate flow thickness and viscosity and initial velocity near 50 m/s). On the bases of matrix of physically reasonable dynamic input parameters a data base of flow patterns has been created. This may represents a specific reference for hazard evaluation on Somma-Vesuvius. The range of flow patterns generated by the direct approach was sampled for inverse analysis of eruptive conditions and rehology of the historical pyroclastic flows associated with the 79 A.D. and 1631 A.D. Plinian and sub-Plinian eruptions. The results of inversion suggest that flows were compatible with Bingham rehology (yield strength = 600 Pa), initial velocity ranging between 50 and 100 m/s, viscosity ranging between 30 and 700 Pa s, and flow thickness ranging between 2

RADAR OBSERVATIONS OF THE 1996 MT RUAPEHU VOLCANO, NEW ZEALAND

Alan Seed **Geoff Austin** .
University of Auckland Physics Department, Private Bag 92019, Auckland, New Zealand

Abstract

A mobile weather radar was deployed at a range of 5 kilometres from the Mt Ruapehu crater during part of its 1996 eruptions. High resolution (100 m spatial, and six second temporal) images were obtained from the plume of ash. The height of the plume changed rapidly, as did the radar reflectivity which was as high as 55 dBZ. Individual pulses of ash could be tracked and were seen to rise at speeds of up to 15 ms^{-1}.

NUMERICAL MODELING OF SUBAQUEOUS ERUPTIONS AT AKADEMIA NAUK CALDERA LAKE (JANUARY 2, 1996)

V. V. Shuvalov, V. V. Adushkin and I. V. Nemtchinov (Institute for Dynamics of Geospheres, Moscow, 117979 Russia)
S. A. Fedotov (Institute of Volcanology, Petropavlovsk-Kamchatsky, 683006 Russia)

Akademia Nauk volcano eruption began on January 2, 1996 simultaneously with Karymsky volcano eruption. Both volcanoes are situated within Karymsky Volcanic Center at a distance of 6 km one from another. The eruptions were initiated by unusually large earthquake swarm. Violent subaqueous explosions on January 2 took place several times every hour in the 5 km-wide Akademia Nauk caldera lake. Explosion clouds rose to 8 km altitude.
Our model of the phenomenon is based on assumption that foregoing earthquake swarm created a vertical channel (about 1 km in depth and several meters in width) connecting the lake with hot magma chamber. Lake water penetrating to the channel was heated by surrounding hot substance above boiling point at the pressure corresponding to this depth. This caused an explosive-type boiling resulting in vigorous ejection of vapor, water and tephra. An energy of hot water in the channel corresponds to estimates of energy release based on an altitude of cloud rising. At the end of regular eruption a new portion of cold water packed in the channel and the process began at the beginning. The interval between individual eruptions is defined by the time of water heating to boiling point. 2D numerical hydrocode was used to model water ejection, cloud rising and tsunami-like waves formation.

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